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The design and construction of a high vacuum bearing test apparatus.

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THE DESIGN AND CONSTRUCTION OF A
HIGH VACUUM BEARING TEST APPARATUS

by
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Massachusetts Institute of Technology

B.S. in M.E. May 21, 1962

THE DESIGN AND CONSTRUCTION OF A

HIGH VACUUM BEARING TEST APPARATUS

by

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ACKNOWLEDGEMENTS

I would like to thank my thesis advisor, Prof. R. W Mann for his encouragement and guidance throughout this project.

This thesis was sponsered by the Harvard Solar Satellite Project at the Harvard College Observatory. I would like to thank Nathan Hazen and the staff at the Harvard College Observatory for this opportunity and the consideration which they gave me.

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ABSTRACT

The growing interest in the exploration of the universe makes mandatory new machines which must operate under the extreme temperatures and the high vacuum (10^{-6} to 10^{-13} mm Hg.) of outer space. A critical problem is that of developing bearings which will operate for long, unattended periods of time. Conventional bearings cannot be used because the liquid lubricants are quickly evaporated by the low pressure, and the solid lubricants wear or chip away, exposing the clean metal. If two perfectly clean surfaces come in contact, they weld together and then leave a rough surface when they are torn apart. This does not happen in our atmosphere because the metal surface quickly adsorbs films of oxygen and water vapor which act as lubricants.

There are many proposed designs for bearings which can operate under this high vacuum, but there is very little emperical data on the performance and useful life of these bearings. The purpose of this thesis is to design and construct an apparatus which will measure the performance of instrument bearings operating in a high vacuum.

1.1 INTRODUCTION

Man's ideas and ambitions have always been far in advance of the materials necessary to fulfill them. His greatest ambition today is to leave the earth and travel throughout the universe. In any vehicle traveling through space, friction, wear, and lubrication may well constitute the greatest materials problem.

1.2 BACKGROUND

The first extensive study of friction conditions in a vacuum was performed by T. P. Hughes in 1939. He found that the coefficient of friction of copper on copper in a vacuum of 10^{-6} mm Hg. was approximately 10 times the coefficient in air. This same experiment and similar experiments have been performed numerous times since 1939, but all these people were interested specifically in the mechanism of friction and wear.

There had been very little interest in bearing operation in a vacuum until the last few years. This interest was spurred by the development of the orbital satellite. I was first introduced to the problems of bearings operating in a vacuum at the Harvard College Observatory.

During my Senior year at M.I.T., I worked part time on the Harvard Solar Satellite Project. My work there was concerned primarily with the design of a grating drive system for an orbiting solar spectrometer. It was impossible to hermetically seal the spectrometer because it operated in a high ultraviolet frequency range which would not pass through a lens. This made it necessary for all the parts of the spectrometer to be exposed to the high vacuum. The need for bearings to operate in this grating drive system suggested the need for some means of testing bearings in a high vacuum. I chose this to be my Bachelor thesis problem.

1.3 THESIS PROBLEM STATEMENT

The purpose of my thesis is to devise a means for collecting emperical data on bearing performance under space-like conditions. The thesis consists of the designing and the construction of an apparatus that will continuously measure and record the running torque of bearings inside an evacuated bell jar.

2.1 CONVENTIONAL BEARING TECHNIQUES

Lubrication techniques are usually divided into two

general catagories, hydrodynamic lubrication and boundary lubrication. Hydrodynamic lubrication depends upon having a continuous fluid layer separate the two surfaces and exert sufficient pressure to keep them from touching. It is difficult to insure hydrodynamic lubrication on earth,, and even more difficult in space where the low pressure (10^{-6} to 10^{-13} mm Hg.) will make retention of the fluid a problem. In space there is also the increased difficulty of resupply of the lubricant because of long-time unattended operation and the absence of gravity. Moreover, there is the problem of lubricant depositing upon the surface of optical and electrical equipment that might be near by.

In boundary lubrication, the solid surfaces actually rub against each other. A liquid lubricant may or may not be present. On earth, exposed solid surfaces quickly adsorb films of oxygen and water vapor. The surfaces are thus "dirty", and the "dirt" acts as a lubricant and plays a major part in reducing friction under conditions of boundary lubrication. When metal surfaces are clean and free from adsorbed films of atmospheric gases, they commonly tend to weld to each other on contact; wear rates and coefficients

of friction are then very high. The cleaning of surfaces in space takes place by loss of adsorbed gases into the vacuum. Mechanical wear between mating surfaces provides a mechanism for removing any hard oxide coating that might have formed on the surfaces. Once the surfaces are clean, they will tend to stay clean in space.

It has been shown that both conventional types of lubrication are inadequate for long-term space application, but in space as on earth, the load and speed at which the bearing is operated greatly affect its useful life. There are a number of suggested bearing designs that appear to get around the space-imposed problems, but there are little emperical data that can be used in the designing of space vehicles.

2.2.1 PERFORMANCE DATA OF CONVENTIONAL BEARINGS

Every bearing catalog contains charts or nomagrams which aid in the selection of the proper bearing and lubricant for a given application. These charts give the approximate frictional torque and the expected life of the bearing for any combination of load and speed.

There is no analytical method known by which the torque and useful life of a ball bearing can be calculated. All

the performance data found in bearing catalogs were obtained by testing many bearings under a given operating condition and then performing a statistical analysis upon the data. It is necessary to do this at enough load-speed combinations so that smooth curves can be drawn between the points on a graph. These charts, therefore, apply only to well lubricated bearings operating in the earth's atmosphere. Thus, this data is not applicable in choosing a bearing intended to operate in outer space.

2.2.2 PERFORMANCE DATA OF BEARINGS IN A VACUUM.

There are many proposed solutions to the problem of unsatisfactory bearing operation in a high vacuum, but none of these have warranted the rigerous testing necessary to obtain a complete array of performance data.

To choose a bearing for a particular application, it is necessary to test several types of bearings under the actual operating conditions, and then choose the one that gives the most desirable combination of torque and useful life.

The purpose of the bearing test apparatus is to fulfill this need and to eventually collect enough data from

which the above mentioned charts can be completed for any bearing that looks promising for space application.

3. DESIGN CRITERIA

3.1 NUMBER OF TEST STATIONS

Since all bearing performance specifications are statistical, the more bearings tested, the more reliable the processed data will be. In the design of the test apparatus, space was of primary importance because the entire apparatus had to fit inside of a 14-inch bell jar. This limited the number of bearings that could be tested at one time. Another factor which must be considered is the complexity of the apparatus. If it is too complex, it is more subject to mechanical or electrical failure, and it is more difficult to set up for a test run. The complexity of the apparatus also increases its cost.

After considering all the above factors, I chose a criterion of 10 to 20 test stations.

3.2 TEST BEARING LOAD AND SPEED

Conventional instrument bearings are tested at radial and axial loads of 0 to 30 lb, and speeds up to 30,000 rpm.

This results in an overall frictional torque range of 100 to 100,000 milligram millimeters.

I expect bearings in a vacuum to be operated at much lighter loads because of the effect of elastic deformation of the bearing material. The deformation causes the hard oxide coating of the metal to crack and thus exposes the clean metal. For this reason, I thought a maximum radial load of 10 lb and an axial load of 5 lb would be adequate for the testing of instrument bearings in a vacuum.

I chose a maximum test speed of 2000 rpm. because this includes the speed of most electric motors and because I felt a higher speed would introduce vibration caused by unbalanced rotating masses.

3.3 MEASURABLE TORQUE RANGE

Although I am testing at lighter loads and slower speeds than those listed in the catalog, I expect higher torques of bearings operating in a vacuum. This will be especially true if journal bearings are used. For this reason I think the apparatus should be capable of measuring torques from 100 to 1,000,000 milligram-millimeters.

3.4 TEST PRESSURE

Ideally, I would like to test the bearings at a pressure of 10^{-13} mm Hg. which is the pressure beyond 4000 miles from earth. A pressure this low cannot be reached in the laboratory without special equipment and conditions which are not compatible with the tests I wish to perform. Therefore, I have to be satisfied with a pressure of 10^{-7} to 10^{-8} mm Hg. which I can obtain. This pressure corresponds to approximately 250 miles from earth which is equal to or greater than the orbital radius of most of our satellites.

4.1 FUNCTIONAL DESCRIPTION OF BEARING TEST APPARATUS

The drive motor which supplies the torque to the test bearings is mounted under the bell jar base plate. (see Fig. 1) A magnetic drive transmits rotational motion through the base plate to the center drive wheel. A small driven wheel on each test station rides against the center drive wheel. The inner race of the test bearing is rotated by the shaft which passes through the test station driven wheel. A cantilevered spring is used to keep the outer race from rotating. The displacement of the spring is proportional

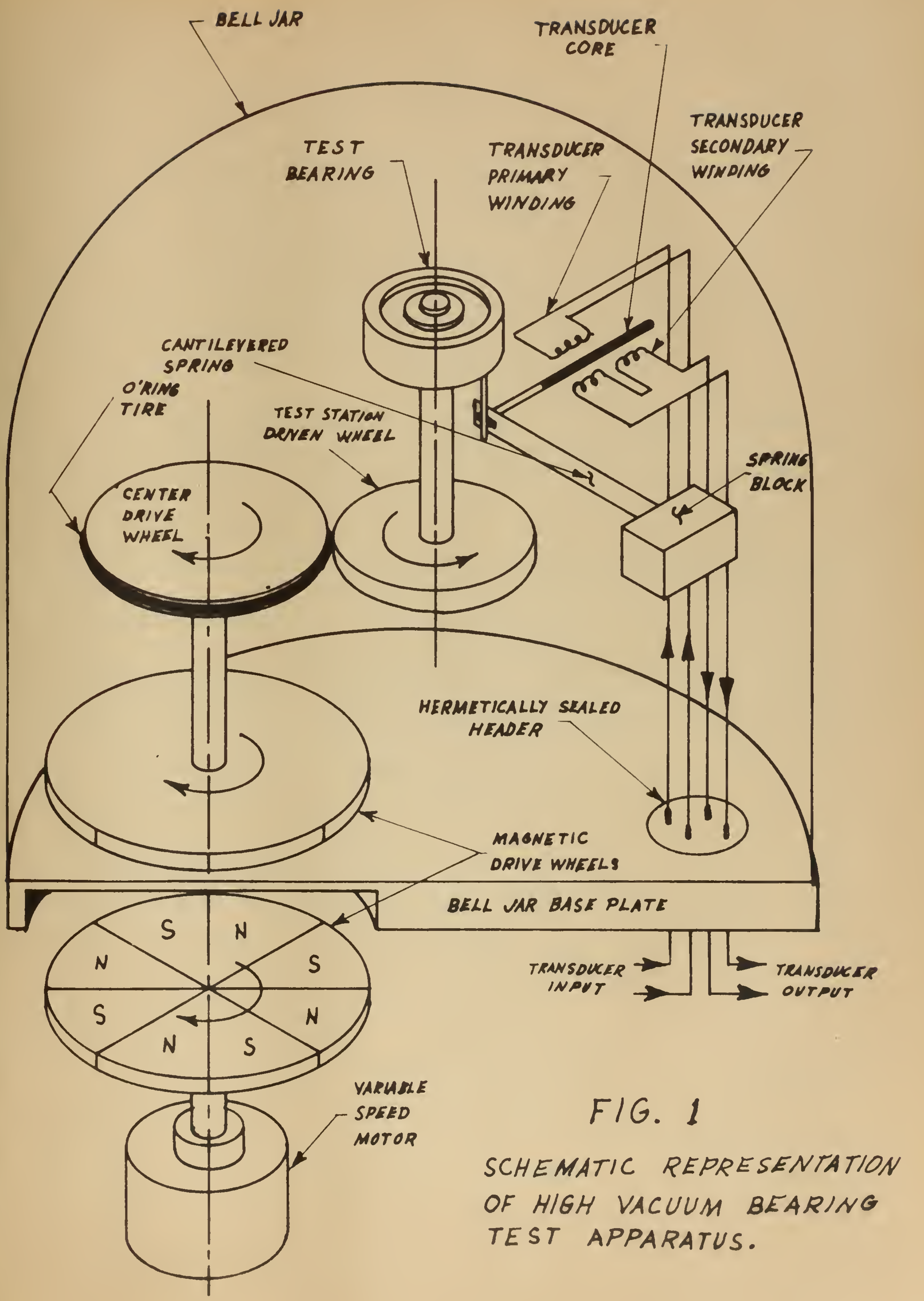


FIG. 1

SCHEMATIC REPRESENTATION OF HIGH VACUUM BEARING TEST APPARATUS.

to the bearing frictional torque, and the displacement of the transducer core attached to the spring determines the amplitude of the signal out of the transducer. Therefore, the signal out of the transducer is proportional to the bearing frictional torque and it can be displayed on a meter or recorded on a strip chart recorder.

The apparatus will be used for the selection of the best type of bearing for a particular application. This will be accomplished by setting the speed and load equal to that of the actual situation and inserting the different types of bearings into the eight test stations. By running tests at a number of combinations of load and speed, bearing torque (or bearing life) vs. rotational speed can be plotted with bearing load as a third parameter.

4.2 COMPONENT DESCRIPTION

The bearing test apparatus is made up of a drive system, eight bearing test stations, and a base plate.

4.2.1 THE DRIVE SYSTEM

The drive system consists of a variable speed DC motor, a magnetic coupling, and a central drive wheel (see Fig. 1). The DC motor (90 to 3000 rpm) is mounted vertically underneath

the bell jar base plate which is a one-inch thick aluminum plate. A recess is milled in the bottom of the base plate to permit the two wheels of the magnetic coupling to be mounted 7/32 inches apart. In the set-up shown in Fig. 2, a plain sheet of 3/16 aluminum plate was used to test the drive system.

Two identical magnet wheels are used to transmit the torque through the base plate (see Fig. 3). One is mounted on the motor shaft and the other one is mounted on a shaft running vertically through the test apparatus base plate. The magnet wheel consists of an aluminum disc with 65 horseshoe magnets mounted in an array such that 13 alternating north and south poles are formed around the disc. It is important to always have like poles adjacent to each other on the disc or some of the magnetic flux lines will be between adjacent magnets rather than through the base plate to the opposite wheel. With a spacing of 7/32 in. between the wheels, a torque of 40 in. oz.(2880 gm cm) can be transmitted by the magnetic coupling.

The center drive wheel which provides the rotational motion to each of the eight test stations is locked to the

Fig. 2 Set-up by which the apparatus drive system was tested.

Fig. 3 One of the magnet wheels of the magnetic coupling.

upper end of the shaft holding the driven magnet wheel. A buna-N o'ring is used as a tire on the center drive wheel to prevent metal to metal contact with the test station wheel. It also prevents vibration from being transferred to the test stations.

4.2.2 THE TEST STATION

The test station block supports a vertical shaft which has locked to it, the wheel that is driven by the center drive wheel. (see Fig. 4 and Dwg. D-5101) The test bearing is placed in a housing and slipped onto the top end of this shaft; the inner race rotates with the shaft, but the outer race is held stationary by a pin in the housing coming in contact with a cantilevered spring. The greater the frictional torque, the more the end of the cantilever spring is displaced. This displacement is measured by a variable reluctance transformer and can be displayed on a meter or recorded by a strip-chart recorder.

To calibrate the bearing test station, it is placed on the calibration jig as shown in fig. 5. The shaft of the test station is brought in contact with a flat on the

Fig. 4 Bearing test apparatus showing the base plate, the center drive wheel and two test stations.

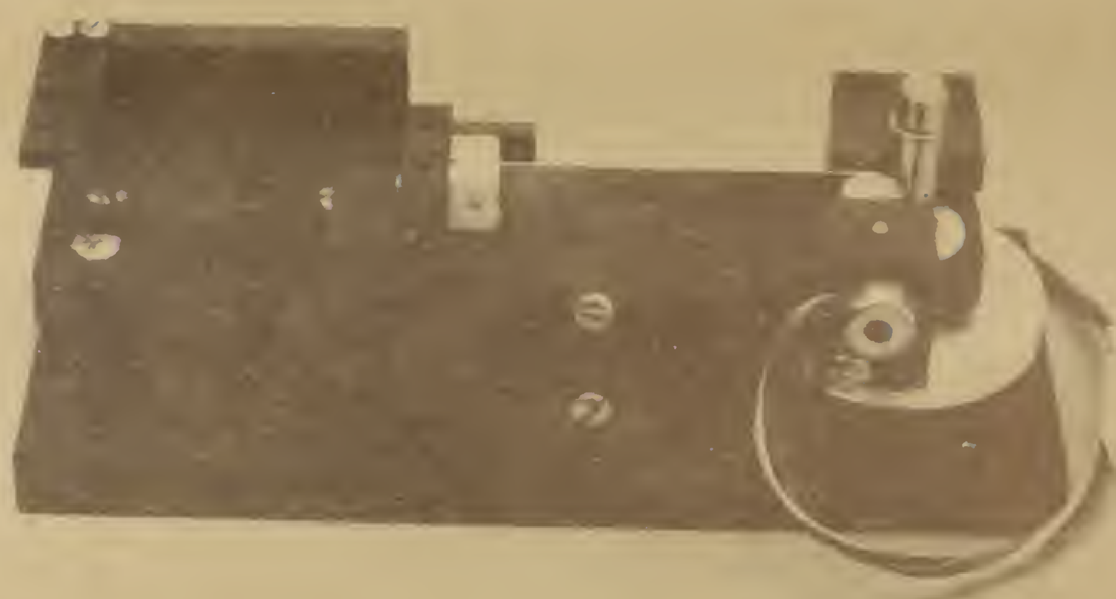


Fig. 5 Test station calibration jig being used to locate knife-edge.

calibration jig. To insure that the force from the bearing housing pin is perpendicular to the cantilevered spring, the knife-edge of the test station is placed on the centerline of the test station block. This is accomplished by adjusting the spring block until the test station knife-edge comes in contact with the one on the calibration jig. Accurate adjustment is obtained by placing an 0-80 screw through the hole of the adjustment bracket of the calibration jig and screwing it into the spring block (see Dwg. B-5105). When the spring block locking screw is loosened, the block can be accurately moved back and forth by turning the 0-80 screw.

To calibrate the transducer of the test station, the calibration jig is placed on its side as shown in fig. 6. The input to the transducer primary is adjusted to a prescribed frequency and amplitude. Weights are then hung on the knife-edge of the test station and the transducer output voltage is read. A force vs. voltage curve can be drawn. The force can be converted to torque by multiplying it by 1/4 in., the torque arm of the bearing housing pin. In

fig. 6, the transducer output voltage was measured on an oscilloscope because an output demodulator had not yet been obtained.

After the transducer has been calibrated, the calibration jig is turned upright again. The test bearing and housing can now be put in place. The bearing is subjected to a radial load by a magnet as of yet not received from the factory. The magnet bracket is held in place by two screws in the holes next to the bearing spring block. The magnetic pull on the bearing housing will be adjusted by changing the separation between the magnet and the bearing housing (see Dwg. D-5101). A record of force vs. separation will have to be made and this will then be used to apply the proper radial load to the bearing. The test station is now ready to be placed on the base plate.

The three calibrations discussed above need be performed only once. The bearing housing can be lifted off without disturbing the magnet, the transducer, or the spring block.

Fig. 6 Calibration jig being used to calibrate torque measuring transducer.

4.2.3 THE BASE PLATE

The base plate supports the center drive wheel which supplies motion to the eight test stations. Eight vertical dowl pins are provided as supports for the test stations (see Fig. 4). A spring plunger is used to hold the test station in contact with the center drive wheel. If one test bearing has failed, that test station can be uncoupled from the center drive wheel by energizing a solenoid. This pivots the test station on its dowl pin support and pulls it away from the center drive wheel. When the test station

is pulled away, a pin drops over the edge of the plunger bracket and holds the test station in place. The solenoid can then be de-energized.

5. OPERATION PARAMETERS OF THE BEARING TEST APPARATUS

After the design was completed, the following operating parameters were available.

Bearing Test Stations	8
Bearing Test Speed	90 to 2000 rpm
Radial Load	0 to 5 lb
Axial Load	.1 to 1 lb
Measurable Torque	100 to 300,000 mg-mm
Test Pressure	10^{-7} to 10^{-8} mm Hg.

Eight bearing test stations was the maximum number I could accomodate without making it necessary to recalibrate each torque measuring device before each test run.

The radial and axial loads must be applied without imposing any torque upon the test bearing. This can be accomplished only by the application of a body force on a symmetrical body. An axial load can be applied by placing weights upon the bearing housing. The bulkiness of the

weights limit the axial load to approximately one pound.

A magnetic force is the only practical body force that can be used to apply a radial load to the test bearing. This limits the radial load to approximately 5 pounds.

The transducer calibration yielded a measurable torque range of 100 to 300,000 mg-mm. If it is found desirable to increase this torque range, the spring specifications can be calculated as prescribed in the appendix.

6. DISCUSSION OF EXPERIMENTAL WORK

6.1 DRIVE SYSTEM

The drive system has been tested and found to transmit 40 in. oz (2880 gm cm) of torque. This is approximately three times the calculated torque required.

Originally there was a 1/8 in. o'ring on the center drive wheel and the test station wheel was pushed against it with constant force. This caused the test station to follow every irregularity in the tire. By replacing the o'ring with a thicker one (3/16 in. wide) and by placing an adjustable stop on the inside of the test station, the

vibrations were eliminated. The thicker o'ring permitted, more deflection of the rubber. The stop held the test station wheel from following every depression in the tire, yet the tire would expand enough so that the two wheels never broke contact.

6.2 TRANSDUCER CALIBRATION

The transducer was first calibrated by placing a micrometer head against the test station knife-edge. The displacement sensitivity was found to be 0.05 volts/0.001 in.

A force calibration was made by hanging weights upon the test station knife-edge. This produced a force sensitivity of 0.040 volts/gram, or a torque sensitivity of .063 volts/gm cm. In the English system, this is 4.54 volts/in. oz. All of the calibrations made were linear within the accuracy of the oscilloscope voltage readings.

6.3 BEARING TESTING

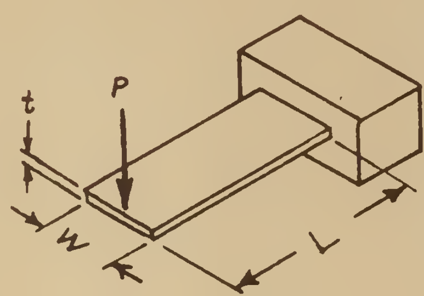
I have two completed test stations. As soon as the vacuum system is put back together, I plan to test two dry ball bearings. If the data looks reliable, I will have the

other 6 test stations manufactured and proceed on a test schedule for testing the performance of solid lubricants in a vacuum.

APPENDIX I. TRANSDUCER SPRING CALCULATION

The range of the measurable torque of the bearing test station can be adjusted to cover most any range simply by changing the spring dimensions. The displacement of the end of the spring (y) is small compared to the spring length(L), therefore a classical cantilevered beam equation can be used.

$$y = \frac{4 \times P \times L^3}{E \times W \times t^3}$$



Choose the maximum displacement equal to 0.030 in.. at maximum torque to be measured.

P = max. torque (in. lb)/0.250 in.

y = 0.030 in.

L = 1.875 in.

E = Youngs Modulus of spring material.

W = Spring width (in.)

t = Spring Thickness (in.)

All the parameters of the above equation are fixed except for W and t. Any combination of W and t can be used so long as W does not excede 0.250 in.

APPENDIX II. CHOICE OF DRIVE SYSTEM

There are many reasons for choosing this particular drive system. First, since any motor must have some type of bearings, it is questionable as to how long a motor could successfully operate in a vacuum. Second, there is no air surrounding the motor in a vacuum, and therefore, there is no means of cooling other than radiation. Third, this source of heat inside the bell jar is undesirable because it makes it more difficult to reach low pressure. Fourth, it is impractical to have a vacuum tight mechanical feed-thru at these low pressures. This leaves very little choice other than a magnetic coupling. The magnetic coupling has the further advantage that it transmits no mechanical vibration from the motor to the test apparatus.

APPENDIX III. CHOICE OF TORQUE MEASURING DEVICE.

There are numerous direct reading torque meters on the market, but these are quite expensive and are not designed to operate at extremely low pressures. Strain gage type transducers were disregarded because one gage would not cover the required range without going to very expensive specials. Variable capacitance type gages were considered, but these were found also to be very expensive and rather short lived with capacitance changing with time. For these reasons, the L.V.D.T. which is a standard item except for the teflon coated leads, was chosen.

The transducer is a linear variable-reluctance differential transformer, Sanborn model #595 DT-50. It is sensitive to 1 microinch of core displacement, but in my case a resolution of only 100 microinches is required.

Another reason for choosing this transducer is that the core can be cantilevered from the spring and thus never come in contact with the transducer coil. This eliminates all friction in the torque measuring device except for the housing pin rubbing against the knife-edge. Most torque

meters depend upon having bearing with a frictional torque an order of magnitude less than the smallest torque measured.

APPENDIX IV. CHOICE OF TEFLON BEARING FOR APPARATUS.

Teflon bearings were choosen to be used in this bearing test apparatus because teflon is rather stable in a high vacuum, and it has low frictional torque for a dry journal bearing. The torque is still relatively high when it is compared with the torque of ball bearings; this is the reason it is not applicable to many situations where the power consumed is of prime importance. Teflon is difficult to machine to close tolerences; this also makes it undesirable because it is difficult to get the proper fit between the bearing and the shaft.

The teflon bearings, used in this test apparatus, were made to Standard bearing dimensions; if a suitable ball bearing can be found for high vacuum operation, it will be a simple matter to change the bearings.

REV	NUMBER
	B-5201

REVISIONS

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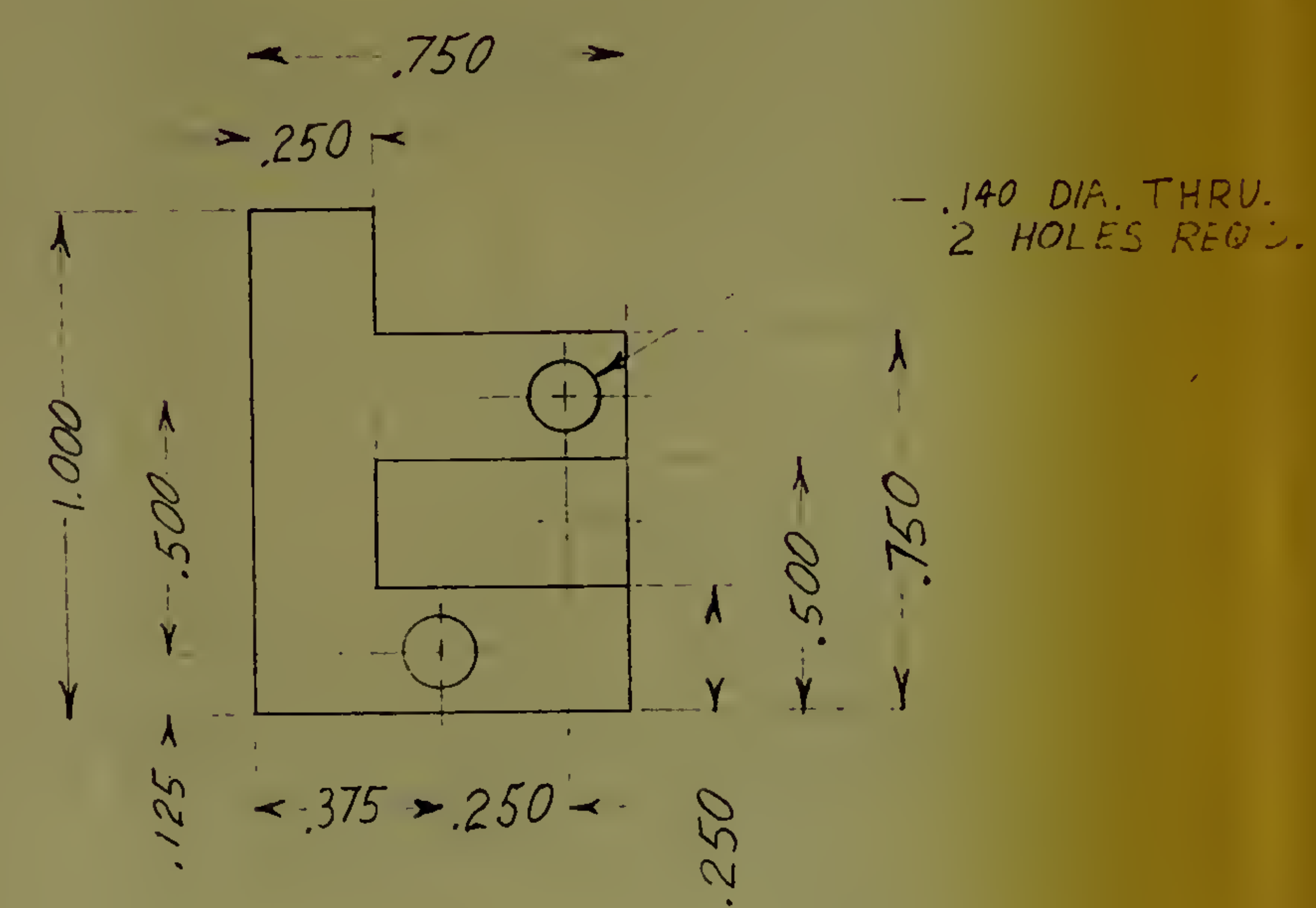
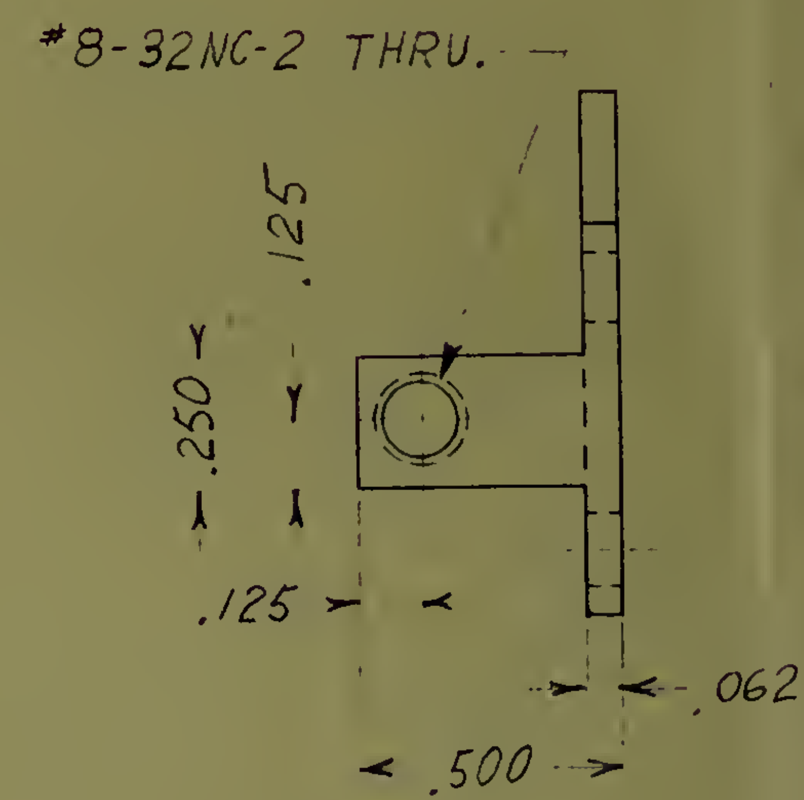




NO	QUAN	NUMBER	DESCRIPTION

UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
±1/64	±.005	± #

MATERIAL & SIZE
2024-T4 ALUMINUM

FINISH
BLACK ANODIZE

APPLICATION

NEXT ASSEMBLY	USED ON
D-5101	

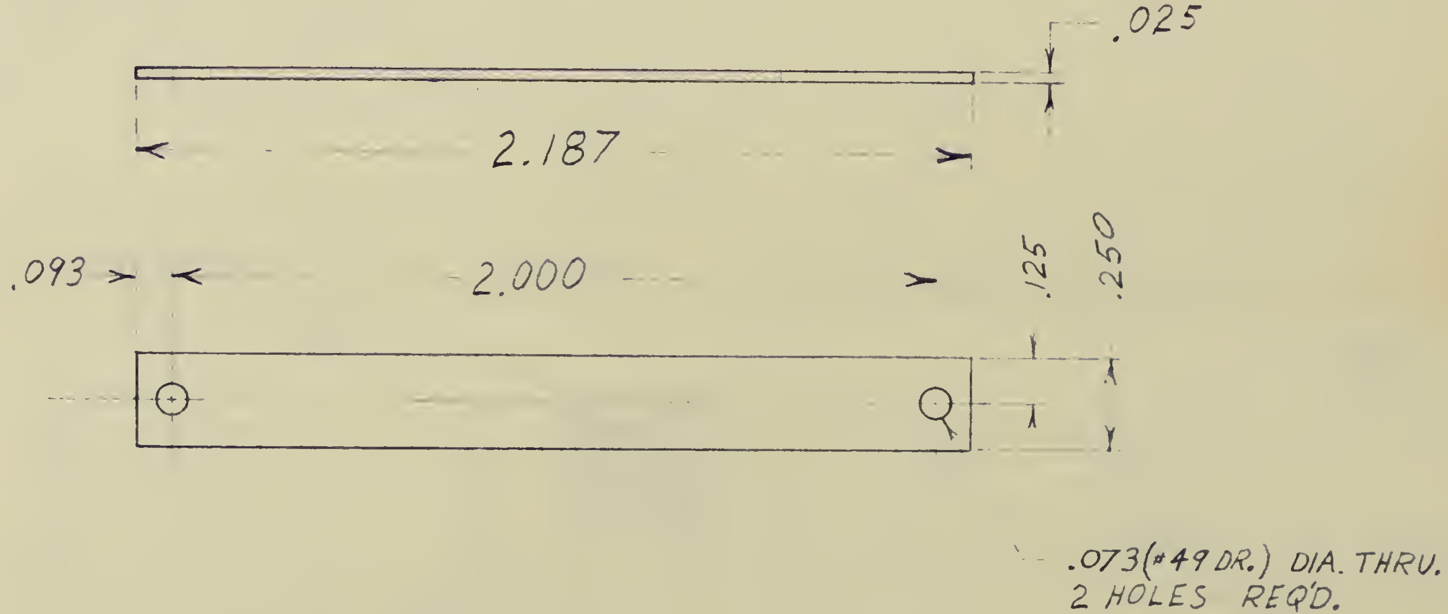
	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	H. d. Walker	2/5/62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE
BRACKET, PLUNGER

SCALE	NUMBER	REV LTR
2/1	B-5201	

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± #	± .003	± #

MATERIAL & SIZE
1095 SPRING STEEL

FINISH
NONE

APPLICATION	
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D-5101	
	,

	SIGNATURE	DATE
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CHECK		
DRAWN	[illegible]	3-14-62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE
SPRING

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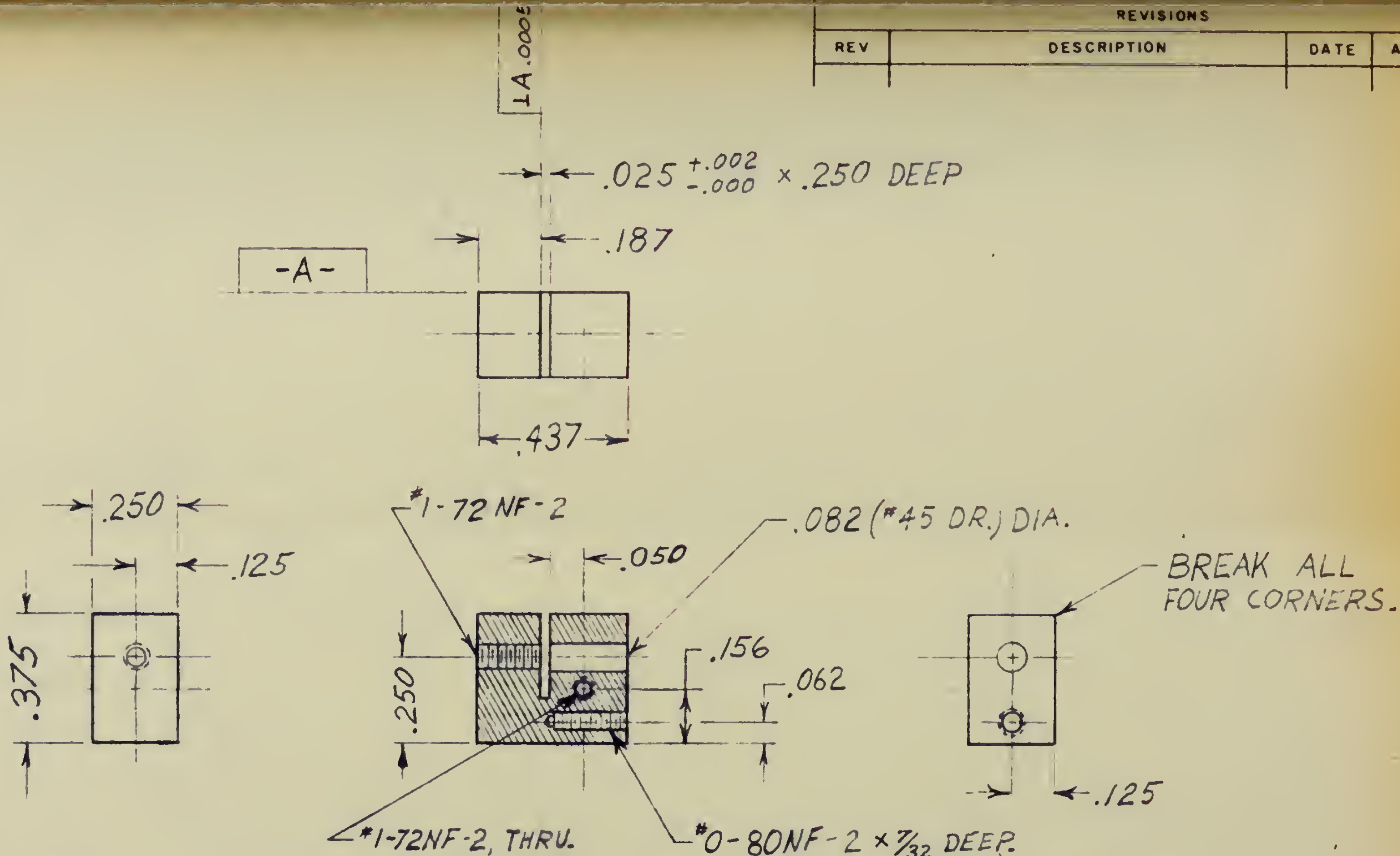

NOTE:
REMOVE ALL BURRS
& SHARP EDGES.

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON		
FRACTIONS	DECIMALS	ANGLES
± 1/64	±.005	± #

MATERIAL & SIZE
2024-T4
ALUMINUM

FINISH
GOLD ANODIZED

APPLICATION		
NEXT ASSEMBLY	USED ON	
D-5101		
APPR	NLH	5/17/62
CHECK		
DRAWN	Mel Walker	12-10-01
	SIGNATURE	DATE

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE
BLOCK, SPRING

SCALE	NUMBER	REV LTR
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34

REVISIONS			
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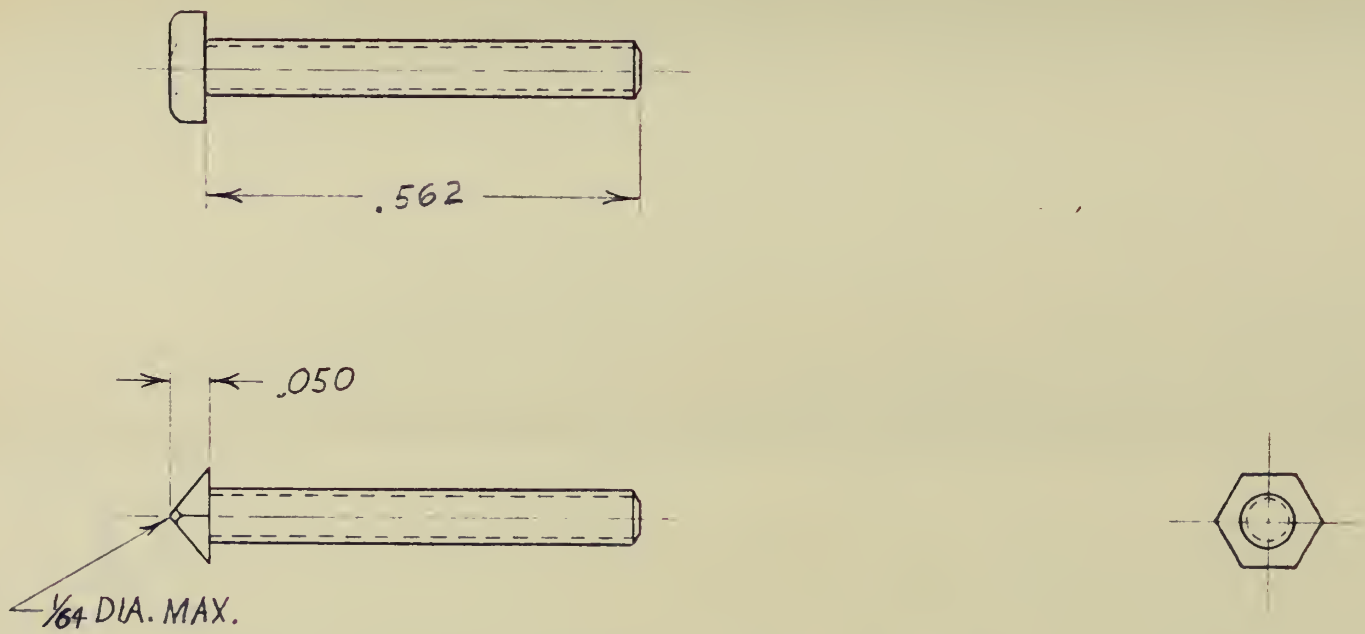

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON		
FRACTIONS	DECIMALS	ANGLES
± 1/64	± .005	± #

MATERIAL & SIZE

1-72NF-2 × 1/2 LG, HEX. HD. S.S.

FINISH NONE

APPLICATION	
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D-5101	

	SIGNATURE	DATE
APPR	NL11	5/17/62
CHECK		
DRAWN	Mel Walker	3-14-62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE KNIFE EDGE

SCALE	NUMBER	REV LTR
4/1	A-5204	

REV | NUMBER B-5205

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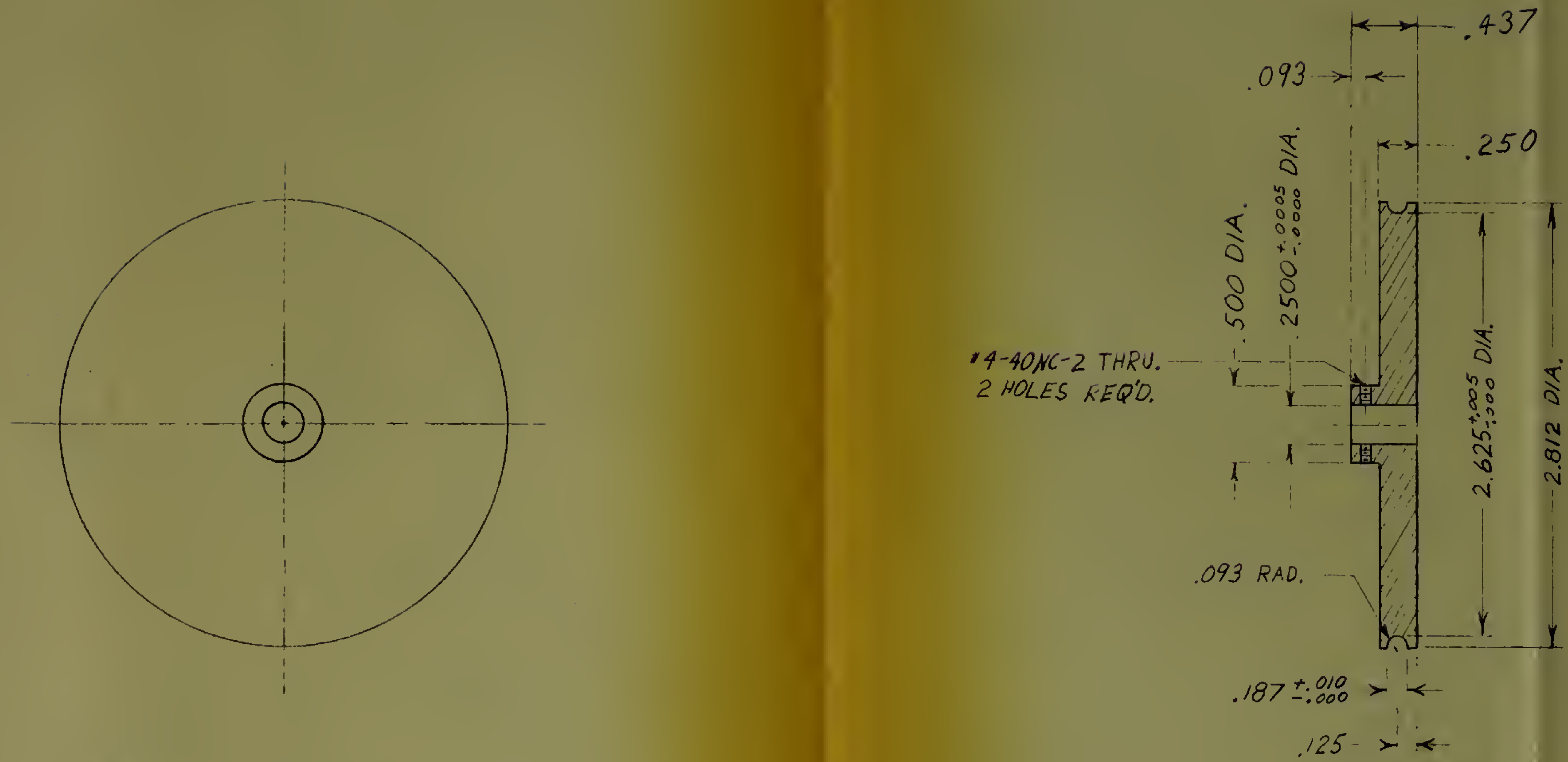

NO	QUAN	NUMBER	DESCRIPTION

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± ~~#~~	± .005	± ~~#~~

MATERIAL & SIZE: 2024-T4 ALUMINUM

FINISH: CLEAR ANODIZED

APPLICATION	
NEXT ASSEMBLY	USED ON
D-5101	

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	Mel Waite	3-16-62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE: WHEEL, DRIVING

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1/1	B-5205	

REV	DESCRIPTION	DATE	APPROVED

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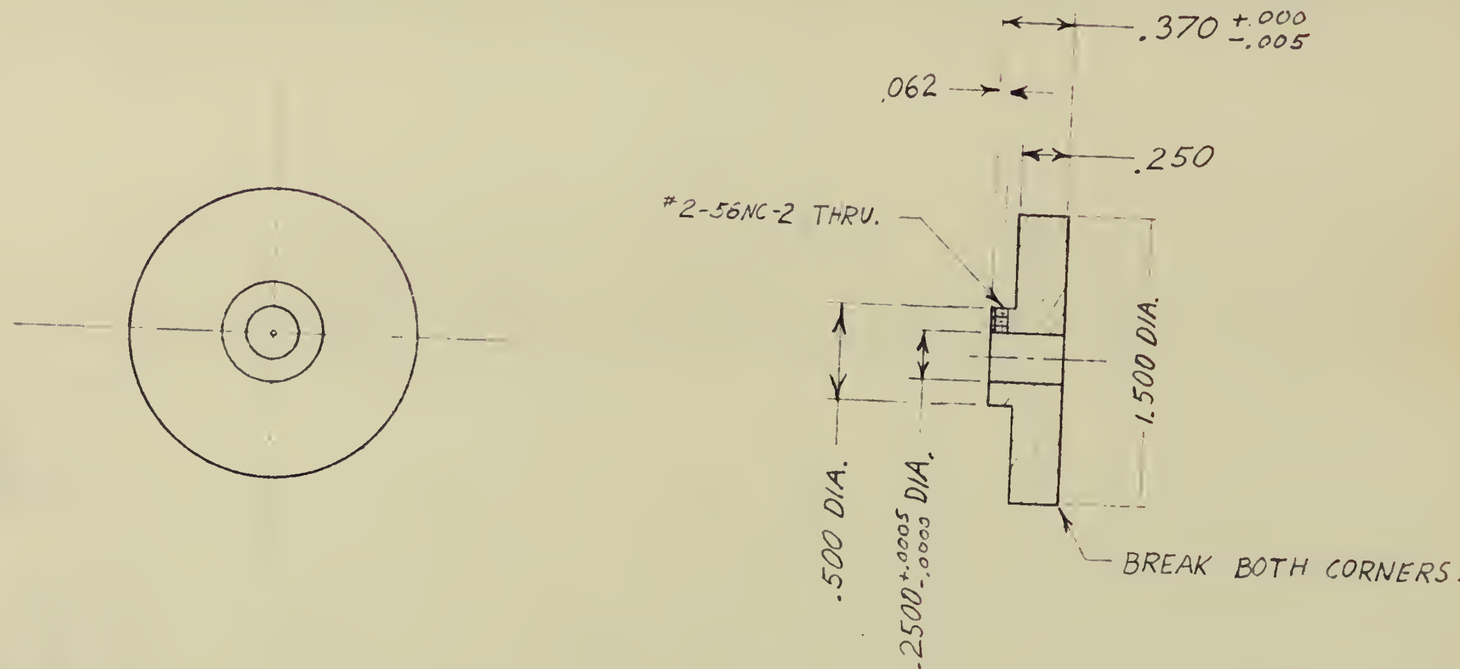

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON			APPLICATION			HARVARD COLLEGE OBSERVATORY CAMBRIDGE 38 MASSACHUSETTS
FRACTIONS ± ⅟₆₄	DECIMALS ±.005	ANGLES ± ⅟₄	NEXT ASSEMBLY D-5101	USED ON		
MATERIAL & SIZE 2024-T4 ALUMINUM			APPR	NLH	5/17/62	TITLE WHEEL, DRIVEN.
			CHECK			
FINISH CLEAR ANODIZED			DRAWN	[illegible]	3-16-62	SCALE 1/1
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36

REV	NUMBER
	B-5207

REVISIONS

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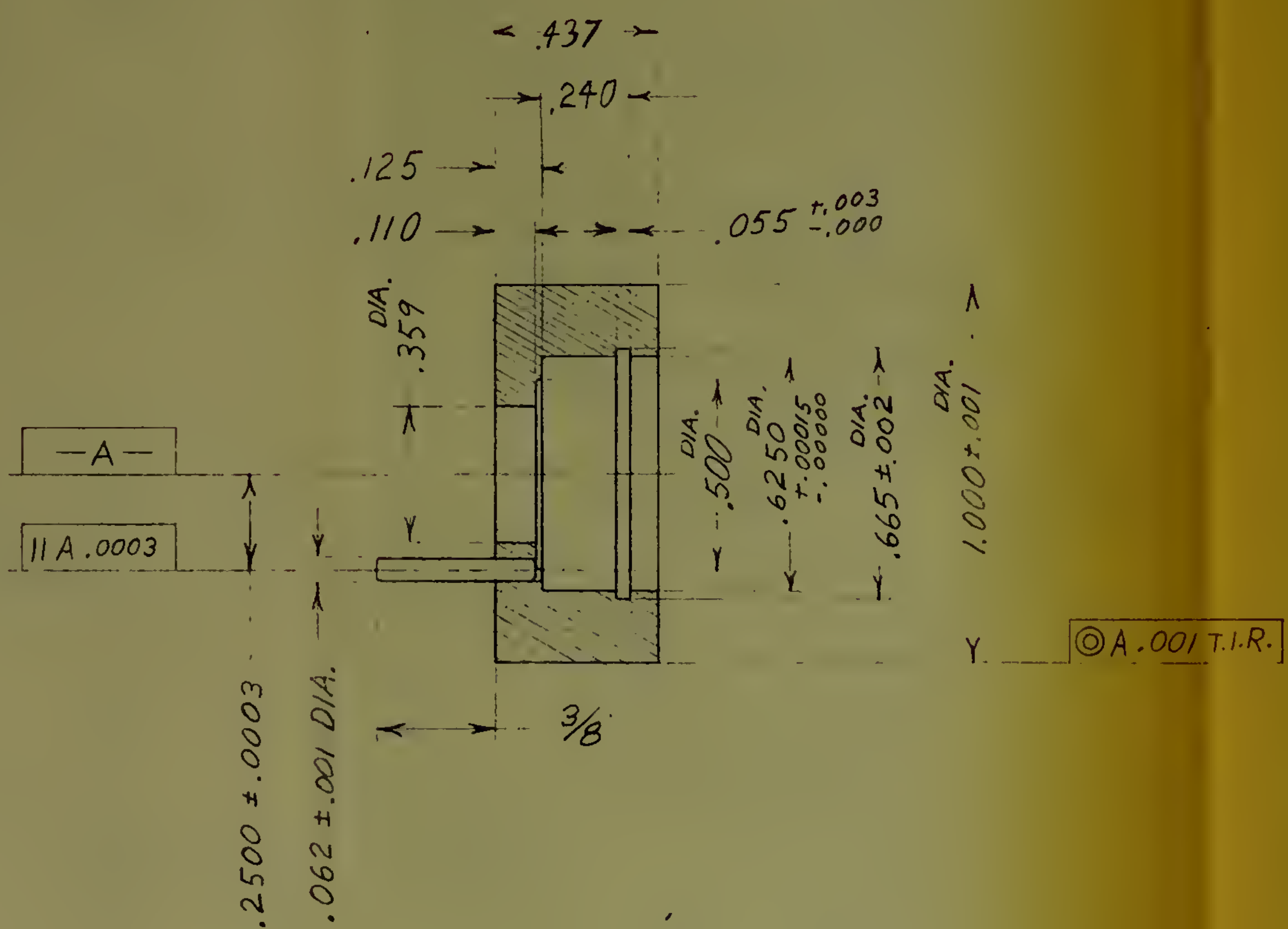
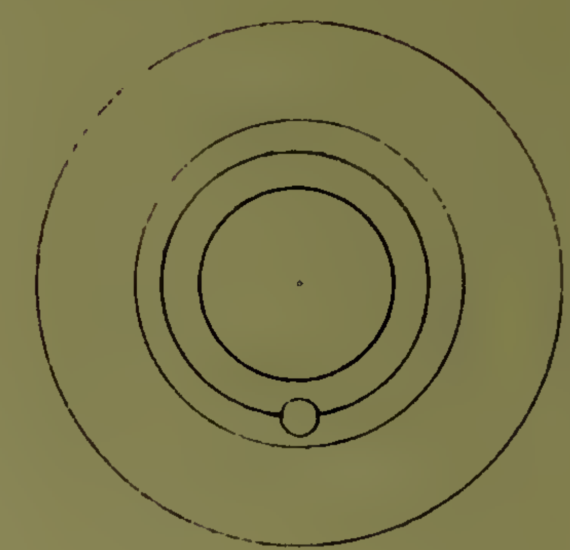




NOTES:
1. REF. LINE -A- IS ℄ OF .6250 DIA.
2. REMOVE ALL BURRS & SHARP EDGES.

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/64	± .005	± ½°

MATERIAL & SIZE

HOUSING:
ANNEALED 1020 STEEL.
PIN: 303 STAINLESS.

FINISH
NONE

NO	QUAN	NUMBER	DESCRIPTION

APPLICATION

NEXT ASSEMBLY	USED ON
D-5101	

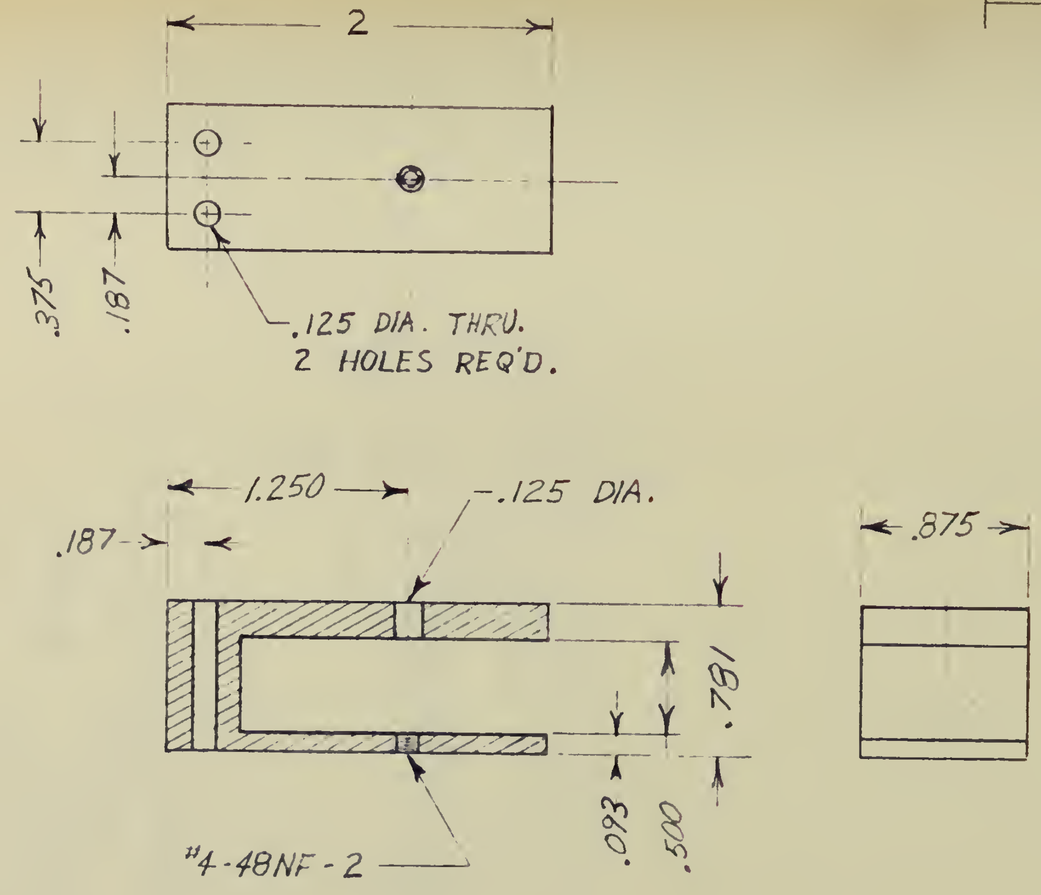
	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	Mel Weiss	2-2-62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE
HOUSING, TEST BEARING.

SCALE	NUMBER	REV LTR
2/1	B-5207	

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON			APPLICATION	
FRACTIONS ± 1/64	DECIMALS ± .005	ANGLES ± 1/4	NEXT ASSEMBLY: D-5101	USED ON
MATERIAL & SIZE: 2024-T4 ALUMINUM				
FINISH: BLACK ANODIZED				

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	[illegible]	-17-62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE: BRACKET, MAGNET

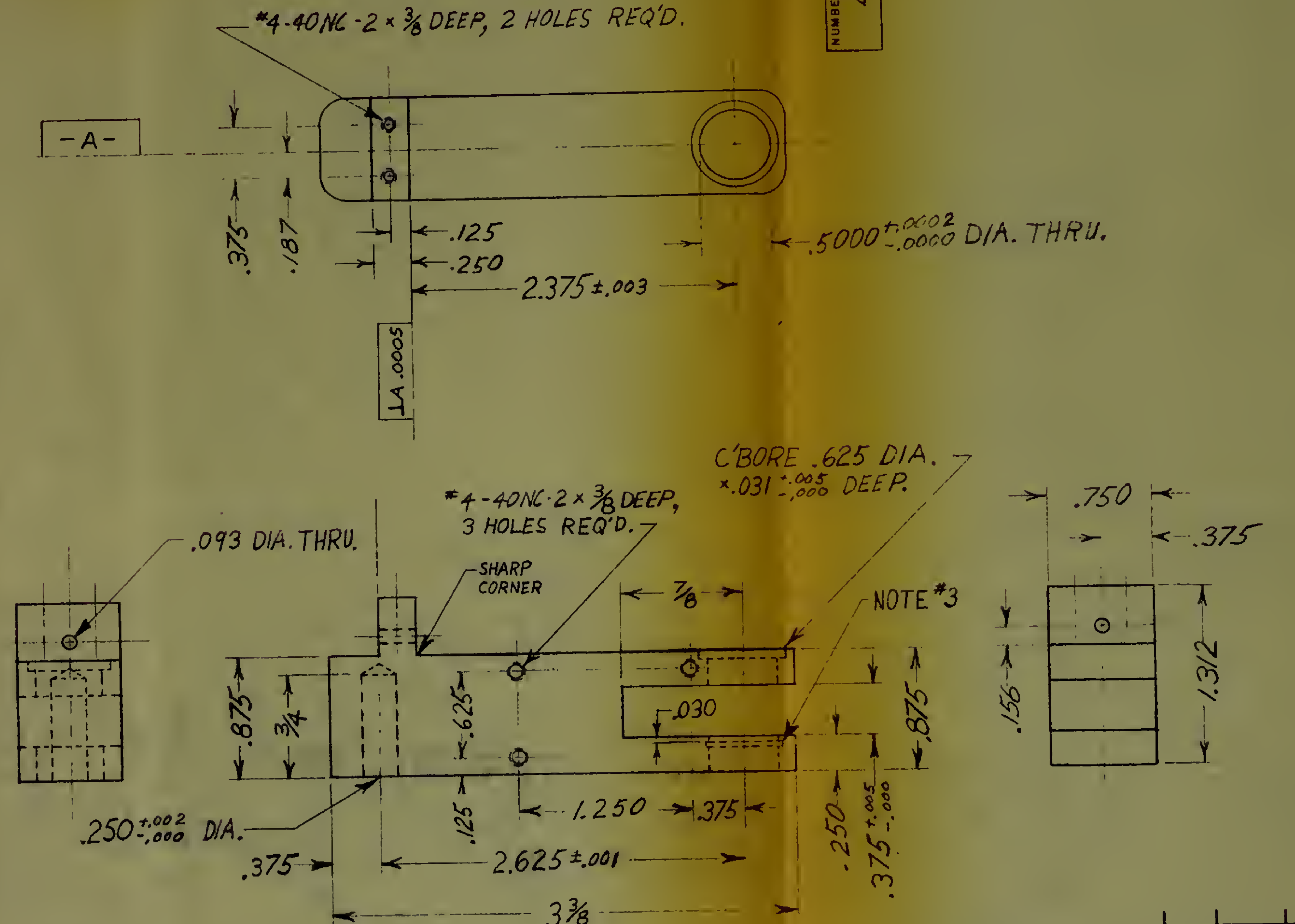
SCALE	NUMBER	REV LTR
1/1	B-5208	

REV	DESCRIPTION	DATE	APPROVED

REVISIONS

REV

NUMBER B-5209



NOTES:

1. REF. LINE -A- IS ℄ OF .250 & .500 BORE.
2. REMOVE ALL BURRS & SHARP EDGES.
3. SNAP RING GROVE DIMENSIONS. .530±.002 DIA × .039 +.002 -.000 WIDE.

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/64	± .005	± #

MATERIAL & SIZE: 2024-T4 ALUMINUM

FINISH: VAPOR BLAST & BLACK ANODIZE.

NO	QUAN	NUMBER

APPLICATION

NEXT ASSEMBLY	USED ON
D-5101	

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	Mel Walker	1/29/62

DESCRIPTION

HARVARD COLLEGE OBSERVATORY

CAMBRIDGE 38 MASSACHUSETTS

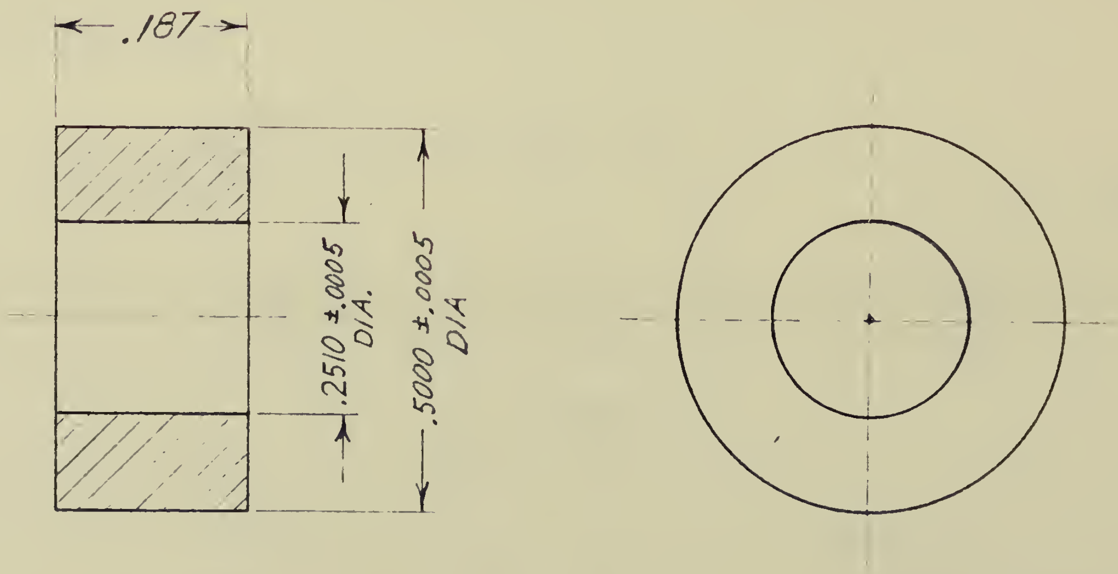
TITLE: BLOCK, BEARING TEST STATION

SCALE: 1/1

NUMBER: B-5209

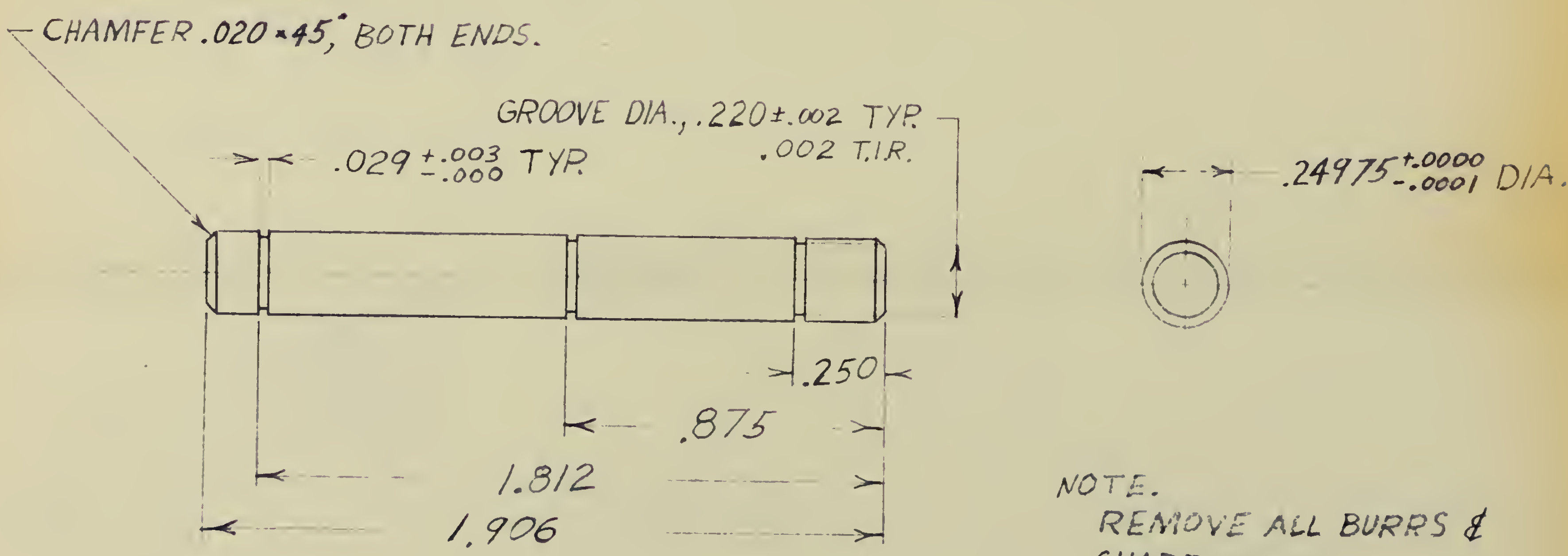
REV LTR

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON			APPLICATION			HARVARD COLLEGE OBSERVATORY CAMBRIDGE 38 MASSACHUSETTS
FRACTIONS ± #	DECIMALS ±.005	ANGLES ± #	NEXT ASSEMBLY: D-5101	USED ON:		
MATERIAL & SIZE: TEFLON			APPR	NLH	5/17/62	TITLE: BEARING, TEFLON, PLAIN.
			CHECK			
FINISH: NONE			DRAWN	M. J. Walker	2-28-62	SCALE: 4/1
				SIGNATURE	DATE	NUMBER: A-5210
						REV LTR:

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



NOTE.
REMOVE ALL BURRS & SHARP EDGES.

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/64	± .005	± 3°

MATERIAL & SIZE

P/C ULTRA PRECISION SHAFTING # A6-20

FINISH

NONE

APPLICATION	
NEXT ASSEMBLY	USED ON
D-5101	

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	McWalden	1/21/61

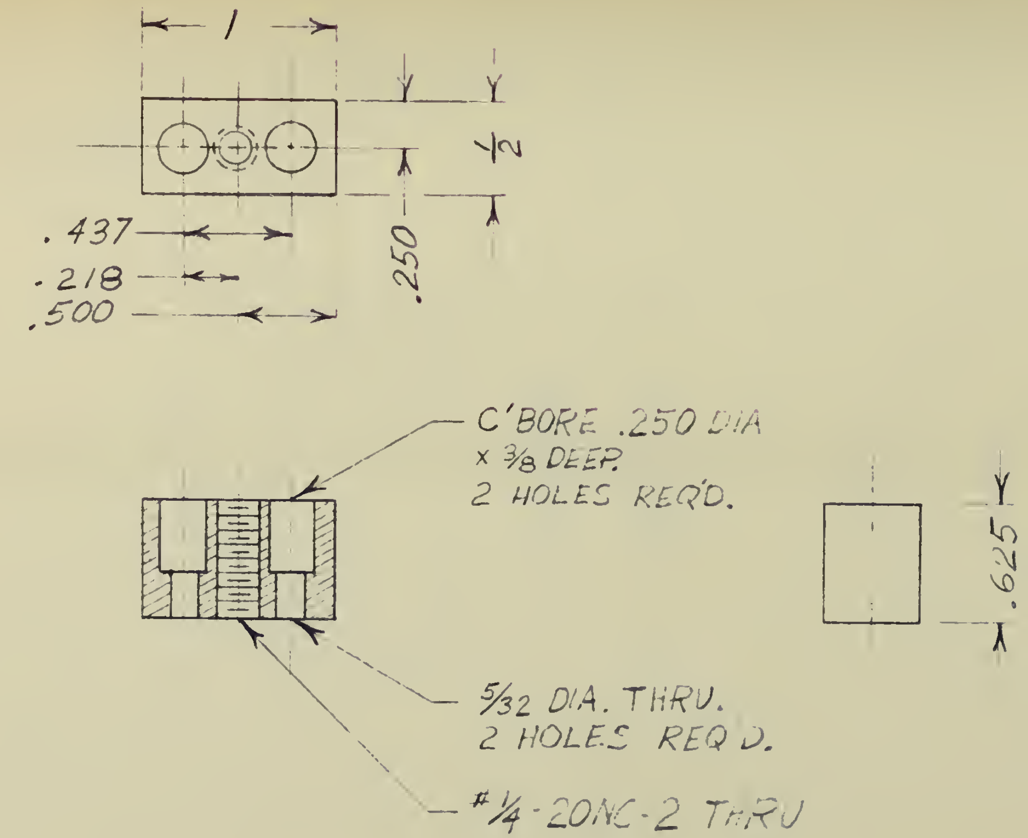
HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE: SHAFT, TEST BEARING

SCALE	NUMBER	REV LTR
2/1	A-5211	

REVISIONS

REV	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/64	±.005	± ½

MATERIAL & SIZE

2024-T4 ALUMINUM

FINISH

A[illegible]

APPLICATION	
NEXT ASSEMBLY	USED ON
D-5101	

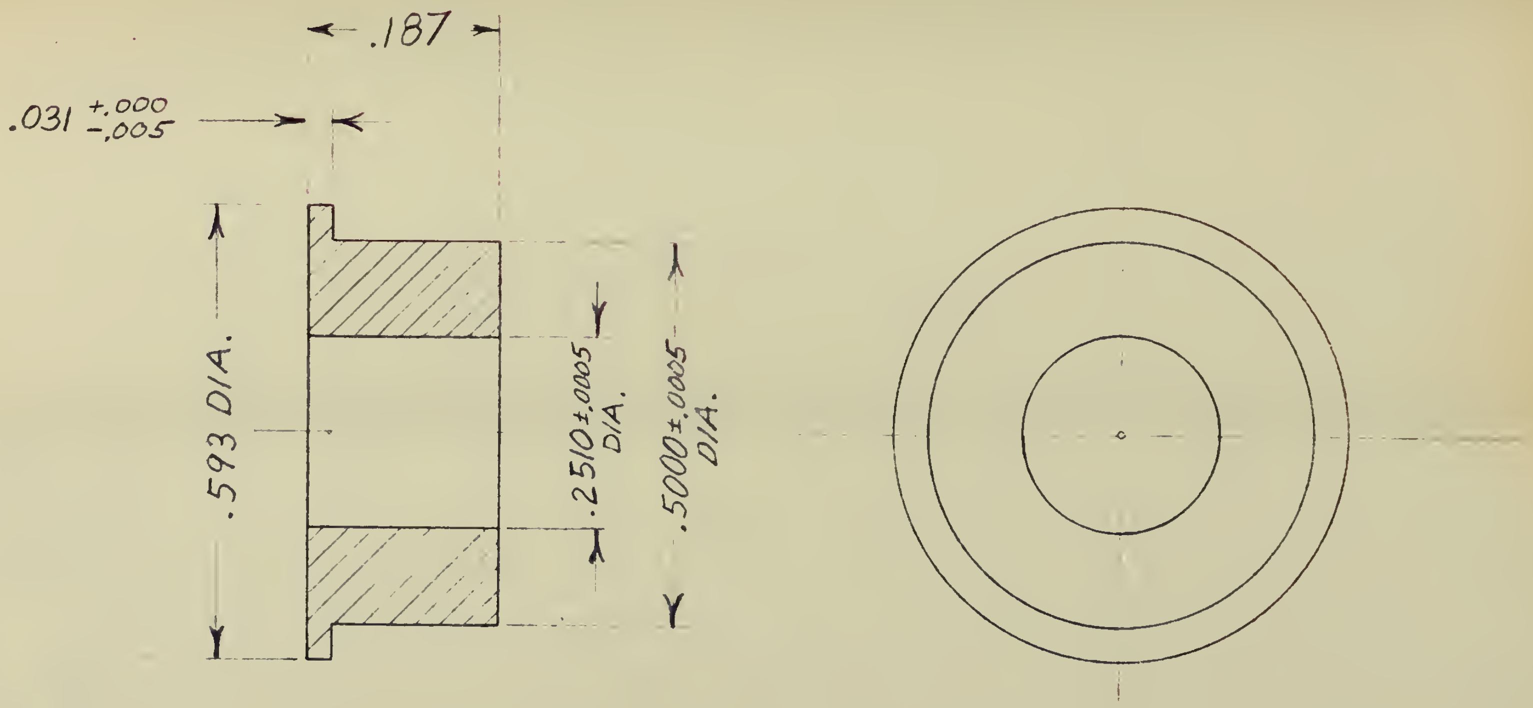
APPR	NL11	5/17/62
CHECK		
DRAWN	[illegible]	5-16-62
	SIGNATURE	DATE

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE
BLOCK, BASE PLATE SUPPORT

SCALE	NUMBER	REV LTR
1/1	A-52[illegible]	

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON		
FRACTIONS ± #	DECIMALS ± .005	ANGLES ± #
MATERIAL & SIZE: TEFLON		
FINISH: NONE		

APPLICATION		
NEXT ASSEMBLY	USED ON	
D-5101		
APPR	NLH	5/17/62
CHECK		
DRAWN	Mel Walker	2-28-62
	SIGNATURE	DATE

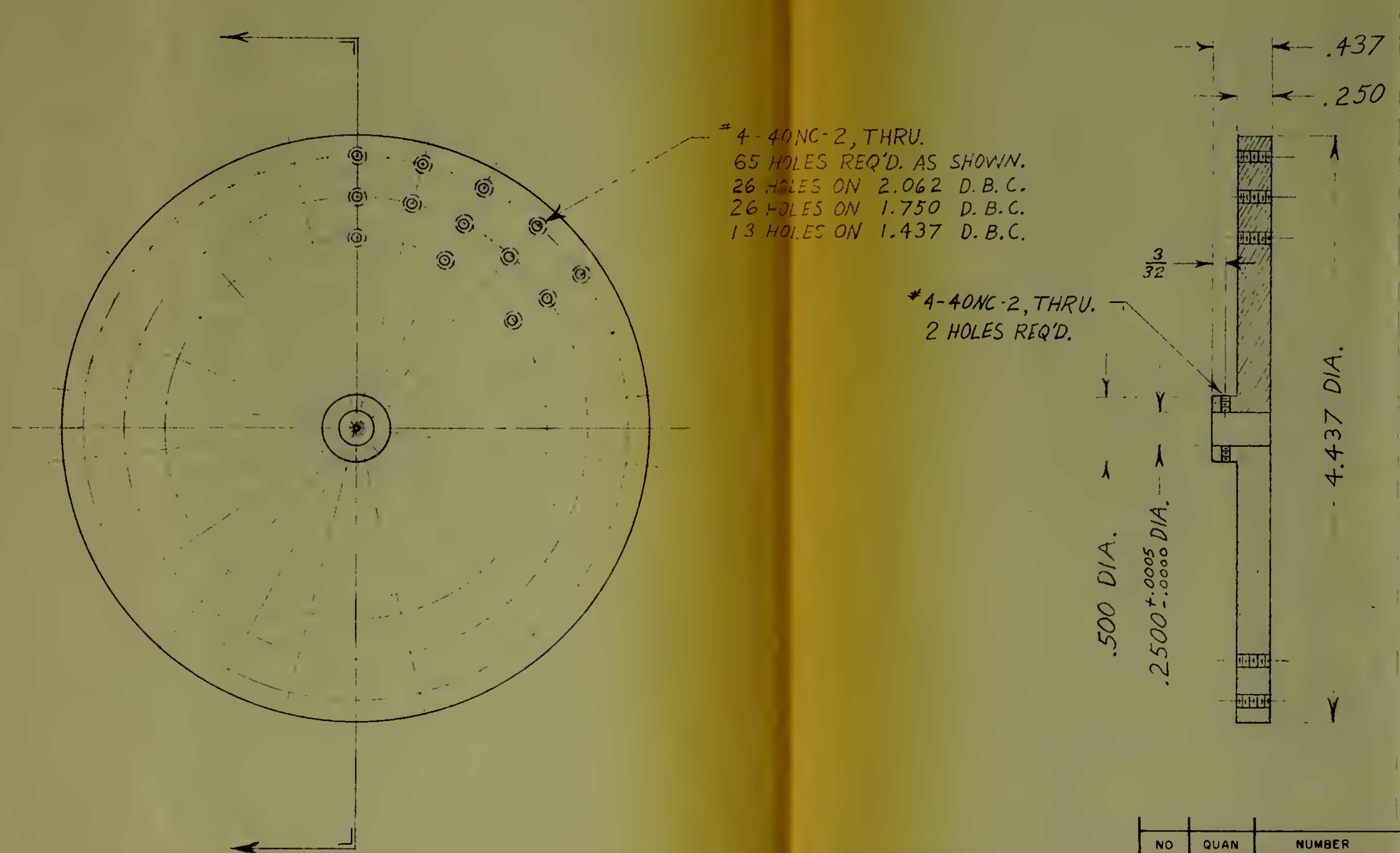
HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE: BEARING, TEFLON, FLANGED.

SCALE	NUMBER	REV LTR
4/1	A-5213	

REV	NUMBER
	B-5214

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



NO	QUAN	NUMBER	DESCRIPTION

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/64	±.005	± 15′

MATERIAL & SIZE

2024-T4 ALUMINUM

FINISH CLEAR ANODIZED

APPLICATION	
NEXT ASSEMBLY	USED ON
D-5101	

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	[illegible signature]	2-23-62

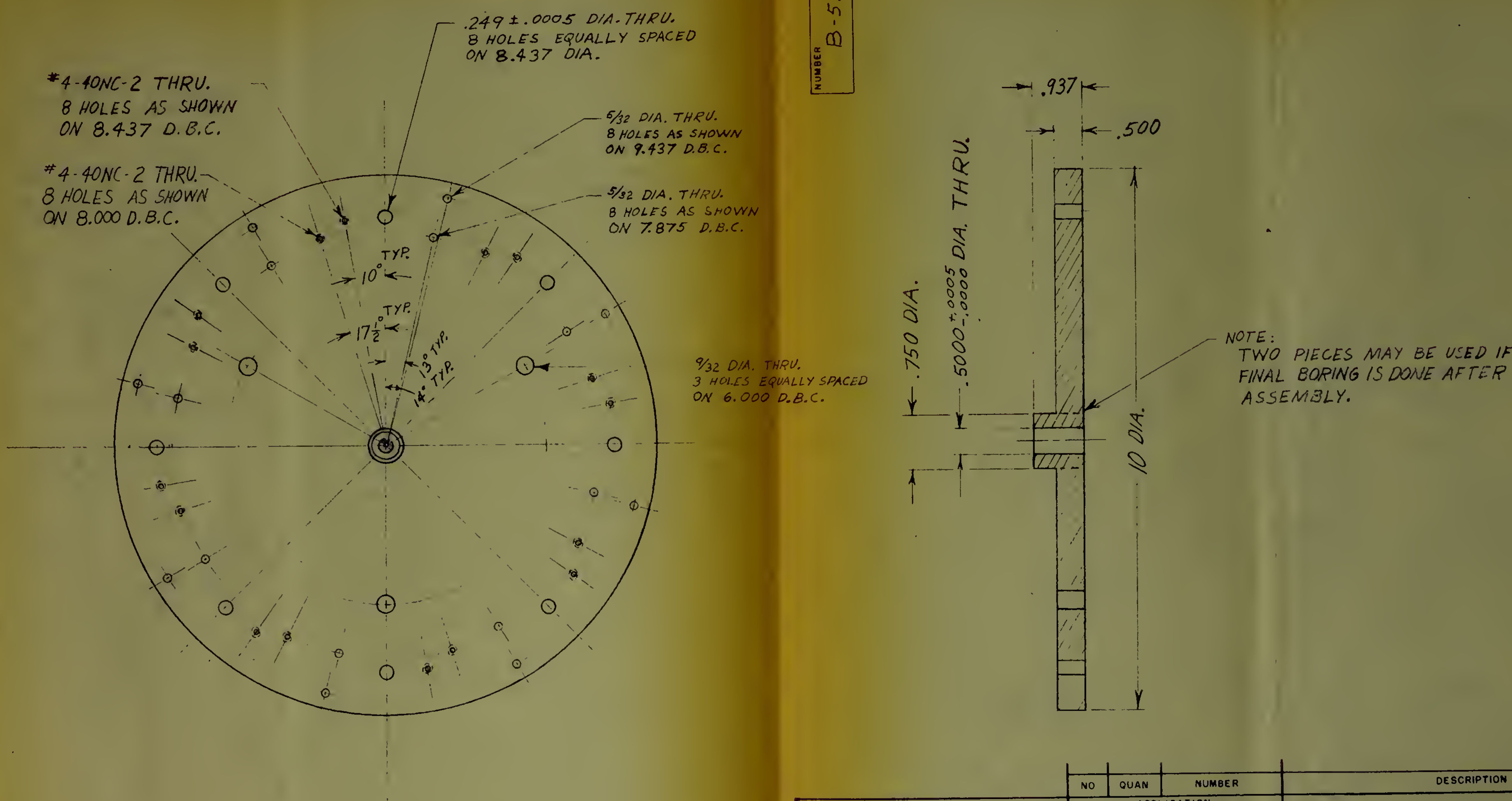
HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE WHEEL, MAGNET

SCALE	NUMBER	REV LTR
1/1	B-5214	

REV | NUMBER B-5215

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



NO	QUAN	NUMBER	DESCRIPTION

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/64	± .005	± 15′

MATERIAL & SIZE: 2024-T4 ALUMINUM

FINISH: BLACK ANODIZE

APPLICATION	
NEXT ASSEMBLY	USED ON
D-5101	

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	Mel Walker	3-7-62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

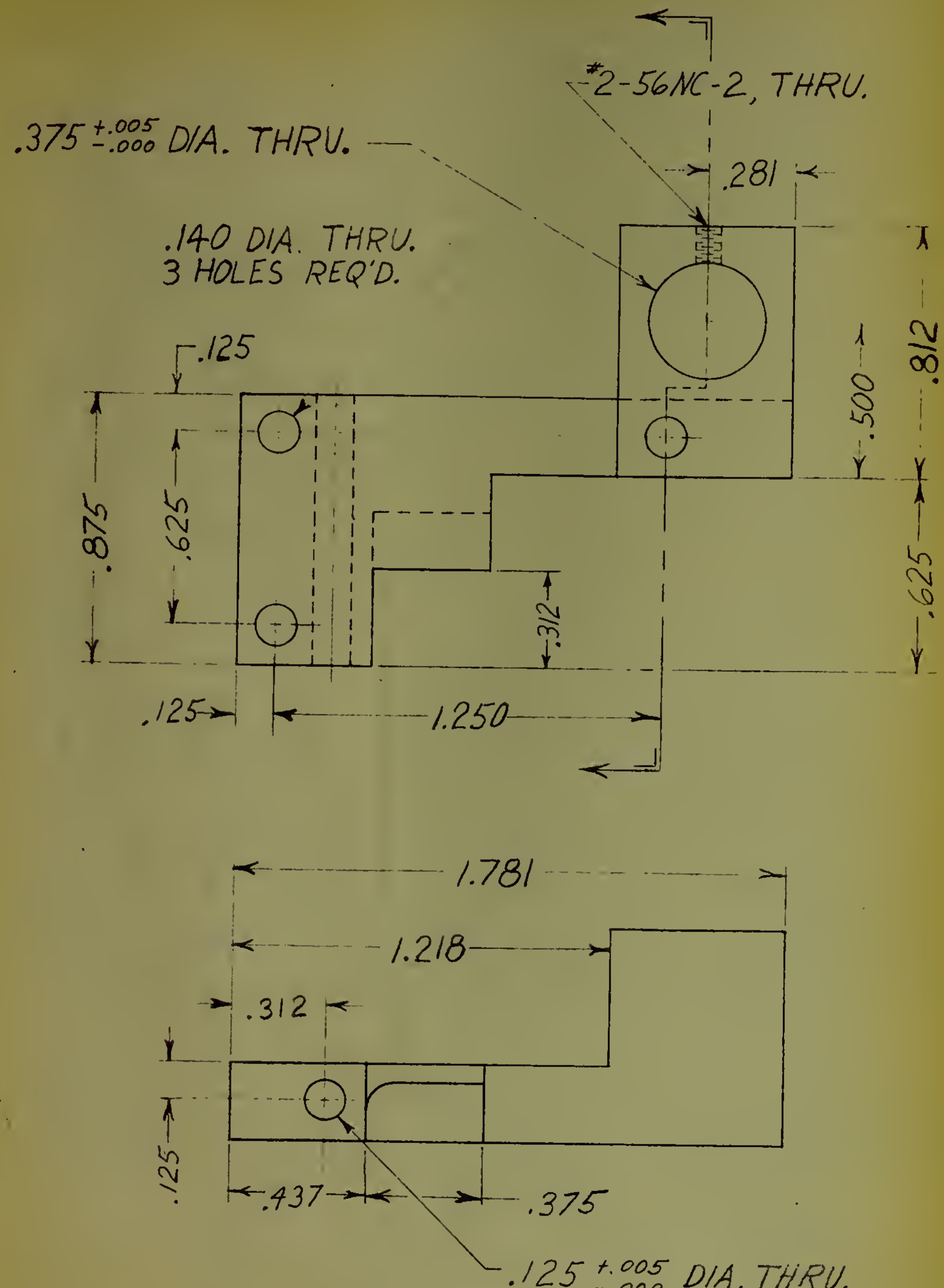
TITLE: PLATE, BASE.

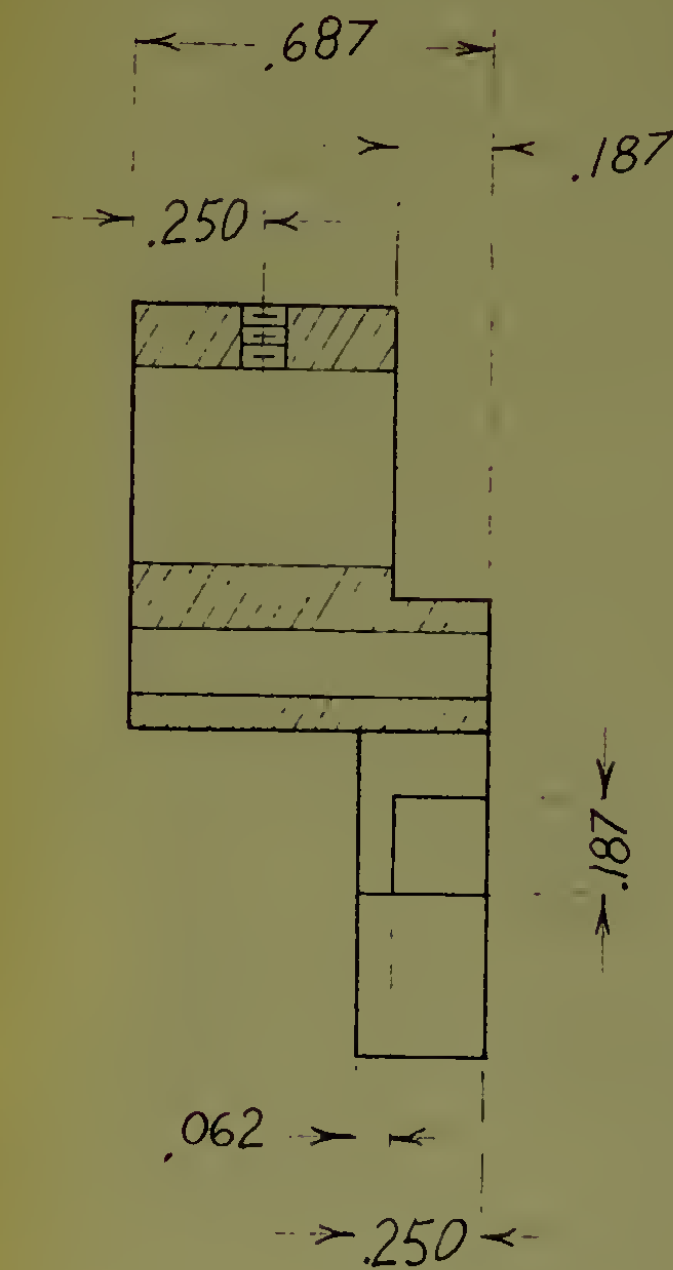
SCALE	NUMBER	REV LTR
1/2	B-5215	

REV	NUMBER
	B-5216

REVISIONS

REV	DESCRIPTION	DATE	APPROVED





UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± #	±.005	± #

MATERIAL & SIZE: 2024-T4 ALUMINUM

FINISH: BLACK ANODIZE

NO	QUAN	NUMBER

APPLICATION

NEXT ASSEMBLY	USED ON
D-5101	

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	[illegible]	2-5-62

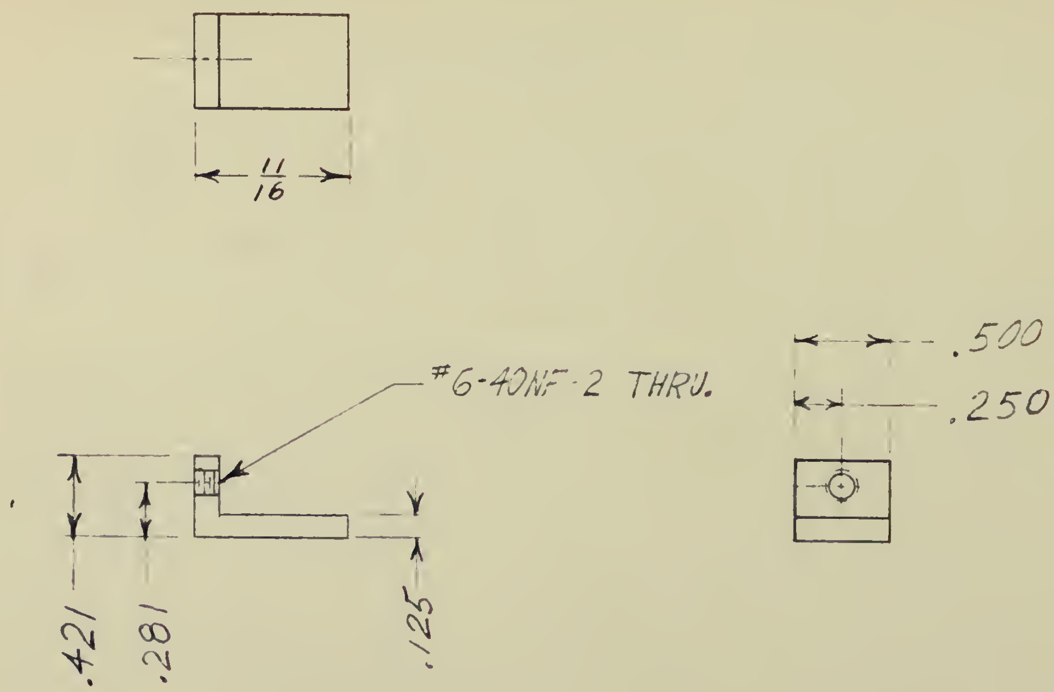
DESCRIPTION

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE: BRACKET, TRANSDUCER

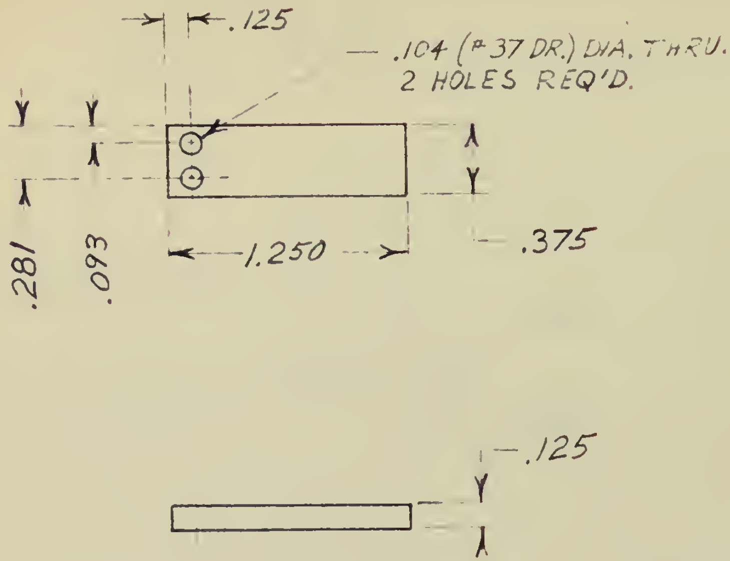
SCALE	NUMBER	REV LTR
2/1	B-5216	

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



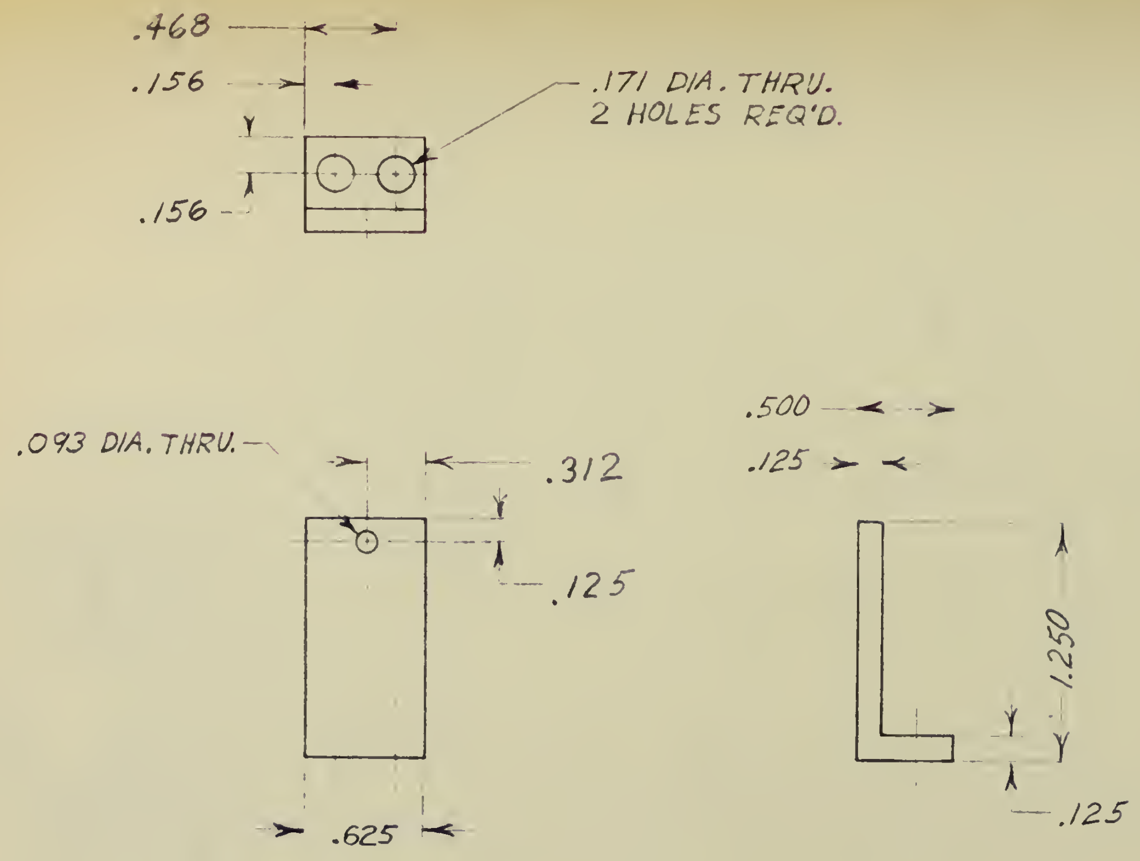
UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON FRACTIONS ± 1/64 DECIMALS ± .005 ANGLES ± ½	APPLICATION: NEXT ASSEMBLY	USED ON		HARVARD COLLEGE OBSERVATORY CAMBRIDGE 38 MASSACHUSETTS	
MATERIAL & SIZE: 2024-T4 ALUMINUM	APPR	NLH	5/17/62	TITLE: STOP, TEST STATION	
	CHECK				
FINISH: NONE	DRAWN	[signature]	5-16-62	SCALE 1/1	NUMBER A-5223 / REV LTR
		SIGNATURE	DATE		

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON FRACTIONS ± 1/64, DECIMALS ± .005, ANGLES ± ½	APPLICATION — NEXT ASSEMBLY: B-5105	USED ON		HARVARD COLLEGE OBSERVATORY, CAMBRIDGE 38 MASSACHUSETTS
MATERIAL & SIZE: 303 STAINLESS STEEL	APPR	NLH	5/17/62	TITLE: RETAINER, TEST STATION
	CHECK			
FINISH: VAPOR BLAST	DRAWN	H. Hoffman	3-10-62	SCALE: 1/1 — NUMBER: A-5217 — REV LTR
		SIGNATURE	DATE	

REV	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON FRACTIONS ± 1/64 DECIMALS ± .005 ANGLES ± ½	APPLICATION: NEXT ASSEMBLY B-5105	USED ON		
MATERIAL & SIZE: 303 STAINLESS STEEL	APPR	NLH	5/17/62	
	CHECK			
FINISH: VAPOR BLAST	DRAWN	McWalker	3-10-62	
		SIGNATURE	DATE	

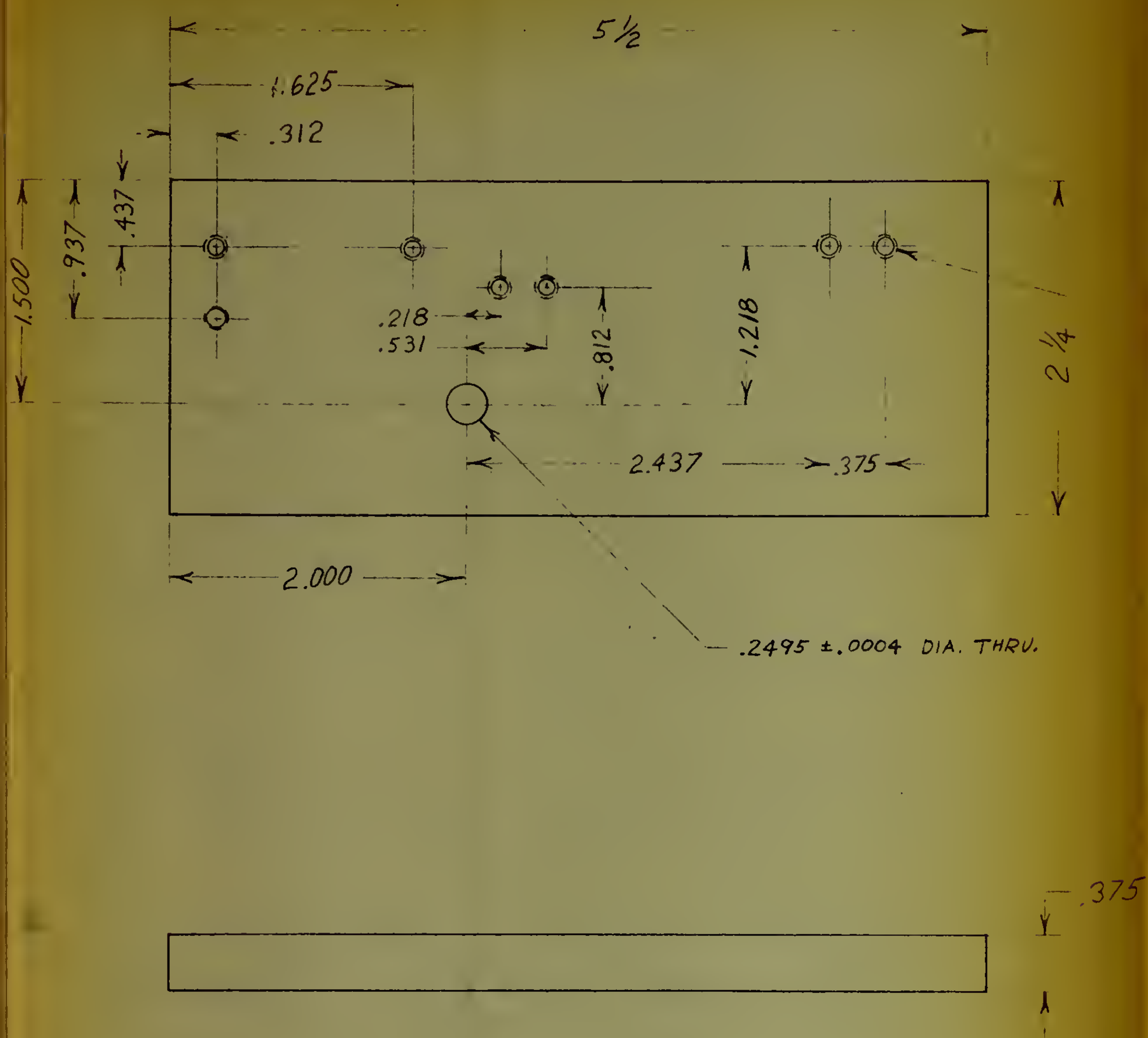
HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE: BRACKET, ADJUSTMENT

SCALE	NUMBER	REV LTR
1/1	A-5219	

REV	DESCRIPTION	DATE	APPROVED

NUMBER B-5220 REV



#6-32NC-2, THRU.
7 HOLES REQ'D AS SHOWN.

NO	QUAN	NUMBER	DESCRIPTION

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/64	± .005	± ½

MATERIAL & SIZE
2024-T4 ALUMINUM

FINISH
BLACK ANODIZED

APPLICATION

NEXT ASSEMBLY	USED ON
B-5105	

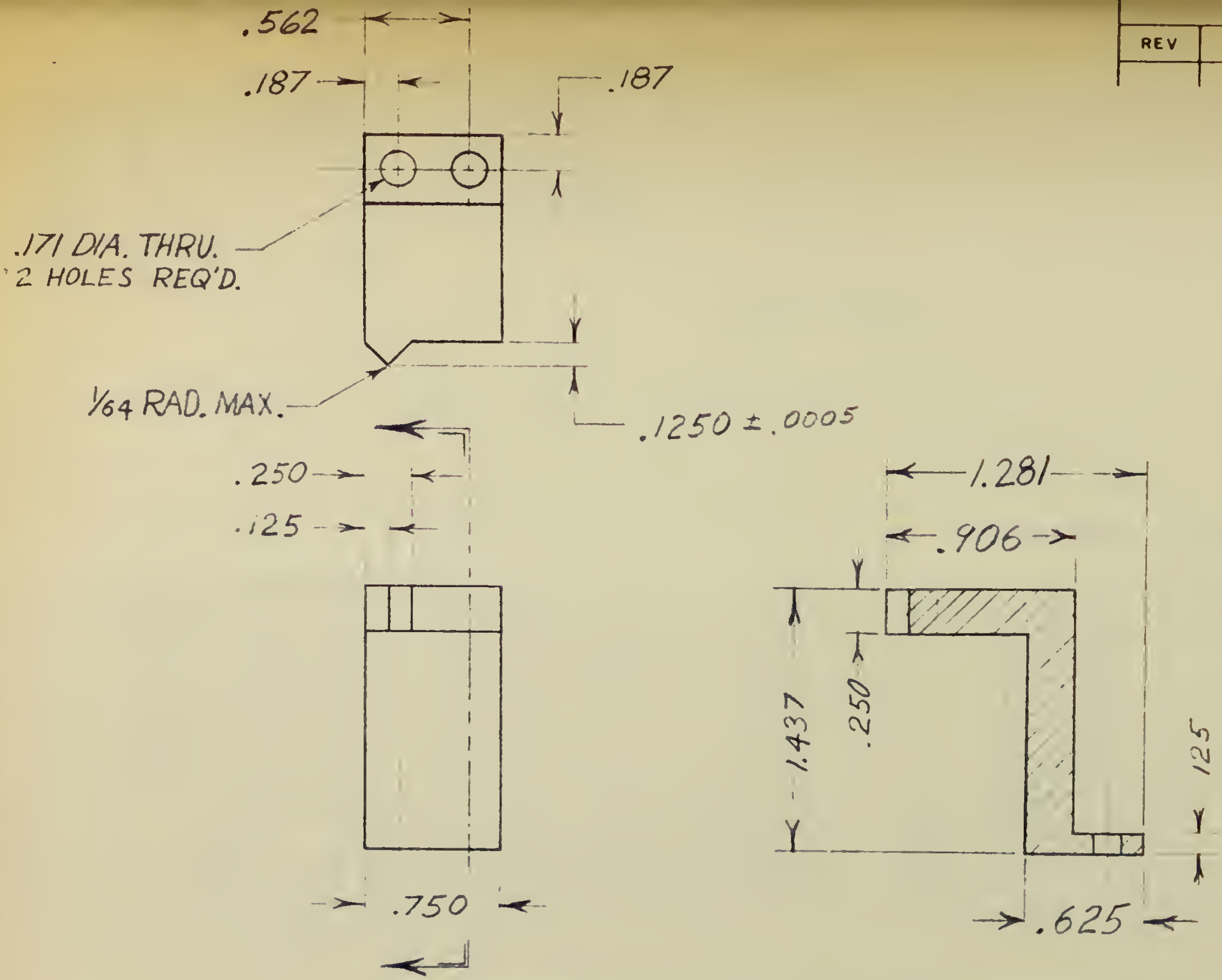
	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	McWalker	3-10-62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE: BASE

SCALE	NUMBER	REV LTR
1/1	B-5220	

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED



UNLESS OTHERWISE SPECIFIED
DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± 1/64	± .005	± ½

MATERIAL & SIZE
303 STAINLESS STEEL

FINISH
YAPOR BLAST

APPLICATION	
NEXT ASSEMBLY	USED ON
B-5105	

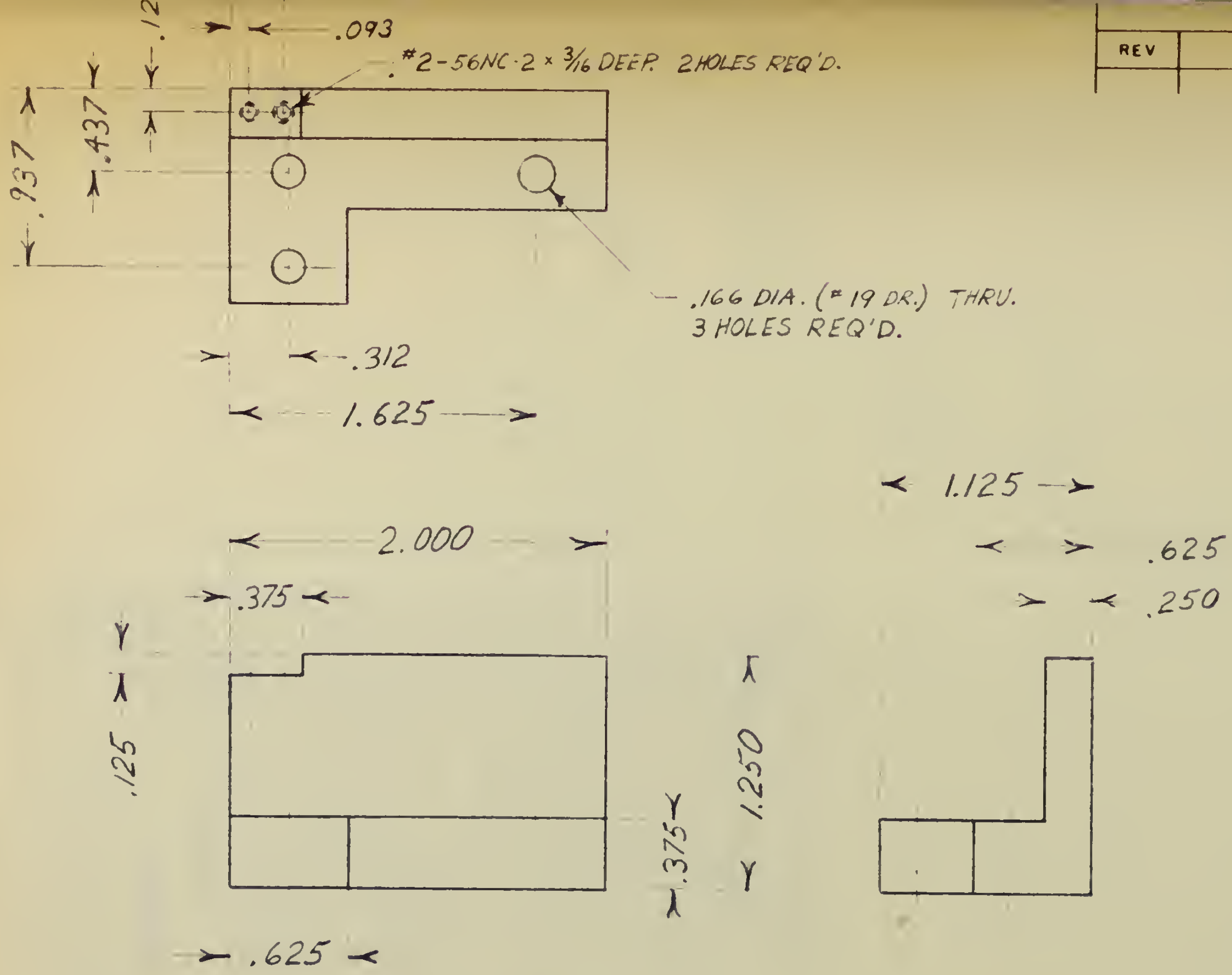
	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	[signature]	3-10-62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE
KNIFE EDGE.

SCALE	NUMBER	REV LTR
1/1	A-5221	

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

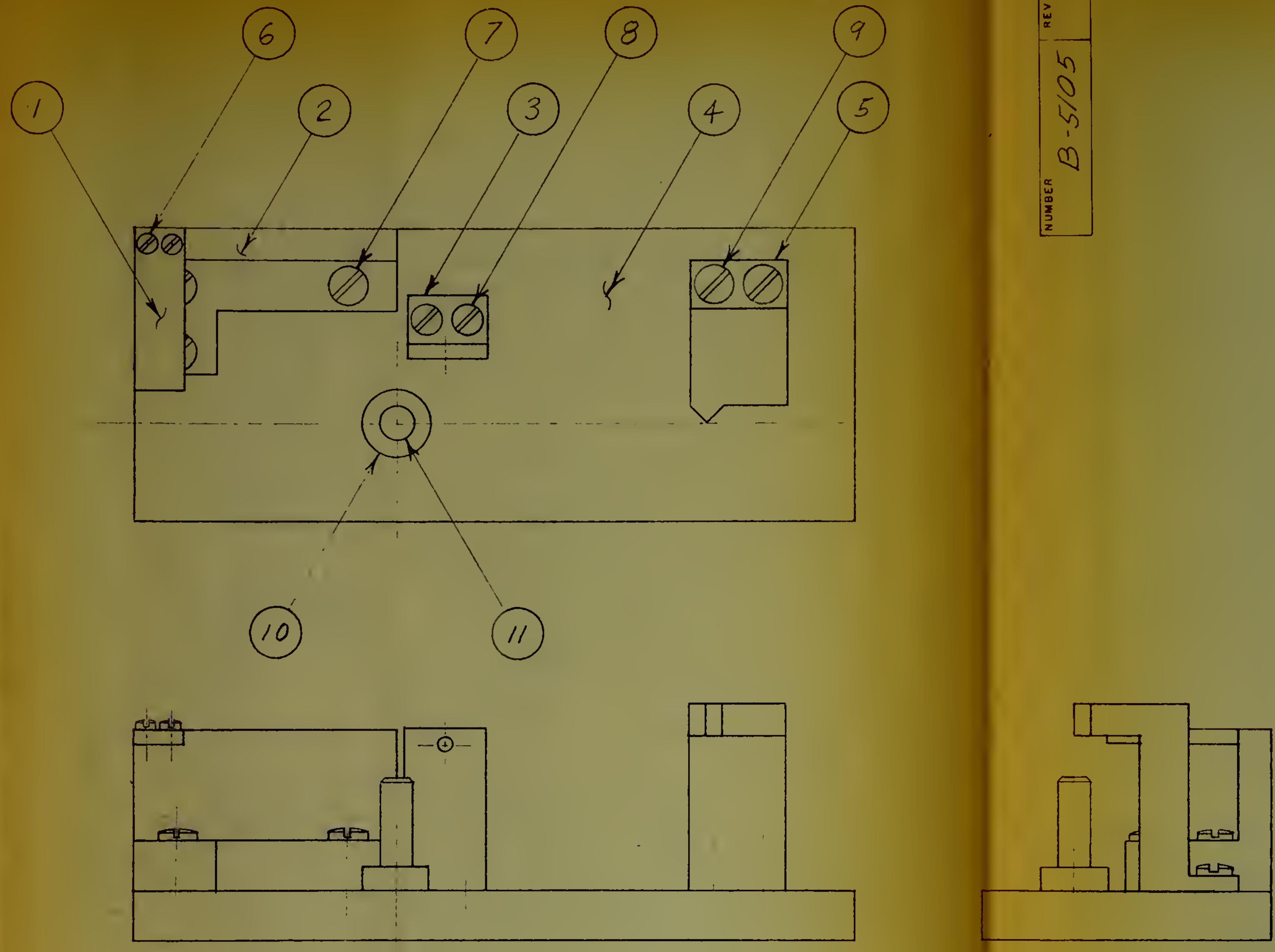


UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON			APPLICATION	
FRACTIONS ± 1/64	DECIMALS ± .005	ANGLES ± ½	NEXT ASSEMBLY B-5105	USED ON
MATERIAL & SIZE: 303 STAINLESS STEEL				
FINISH: VAPOR BLAST				

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	N. Filk. Lu	3 · 10 · 62

HARVARD COLLEGE OBSERVATORY
CAMBRIDGE 38 MASSACHUSETTS

TITLE		
SUPPORT, SIDE.		
SCALE 1/1	NUMBER A-5222	REV LTR



NUMBER B-5105 REV

REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

NO	QUAN	NUMBER	DESCRIPTION
11	1		SHAFT, PIC # A6-13.
10	1		SPACER, PIC # B8-12.
9	2		SCREW, #6-32NC-2 × 3/8 LG, BIND. HD., S.S.
8	2		SCREW, #6-32NC-2 × 3/8 LG, FIL. HD., S.S.
7	3		SCREW, #6-32NC-2 × 5/8 LG, BIND. HD, S.S.
6	2		SCREW, # 2-56NC-2 × 1/4 LG., FIL. HD. S.S.
5	1	A-5221	KNIFE EDGE.
4	1	B-5220	BASE.
3	1	A-5219	BRACKET, ADJUSTMENT.
2	1	A-5222	SUPPORT, SIDE.
1	1	A-5217	RETAINER, TEST STATION.

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS	DECIMALS	ANGLES
± —	± —	± —

MATERIAL & SIZE —

FINISH —

APPLICATION	
NEXT ASSEMBLY	USED ON

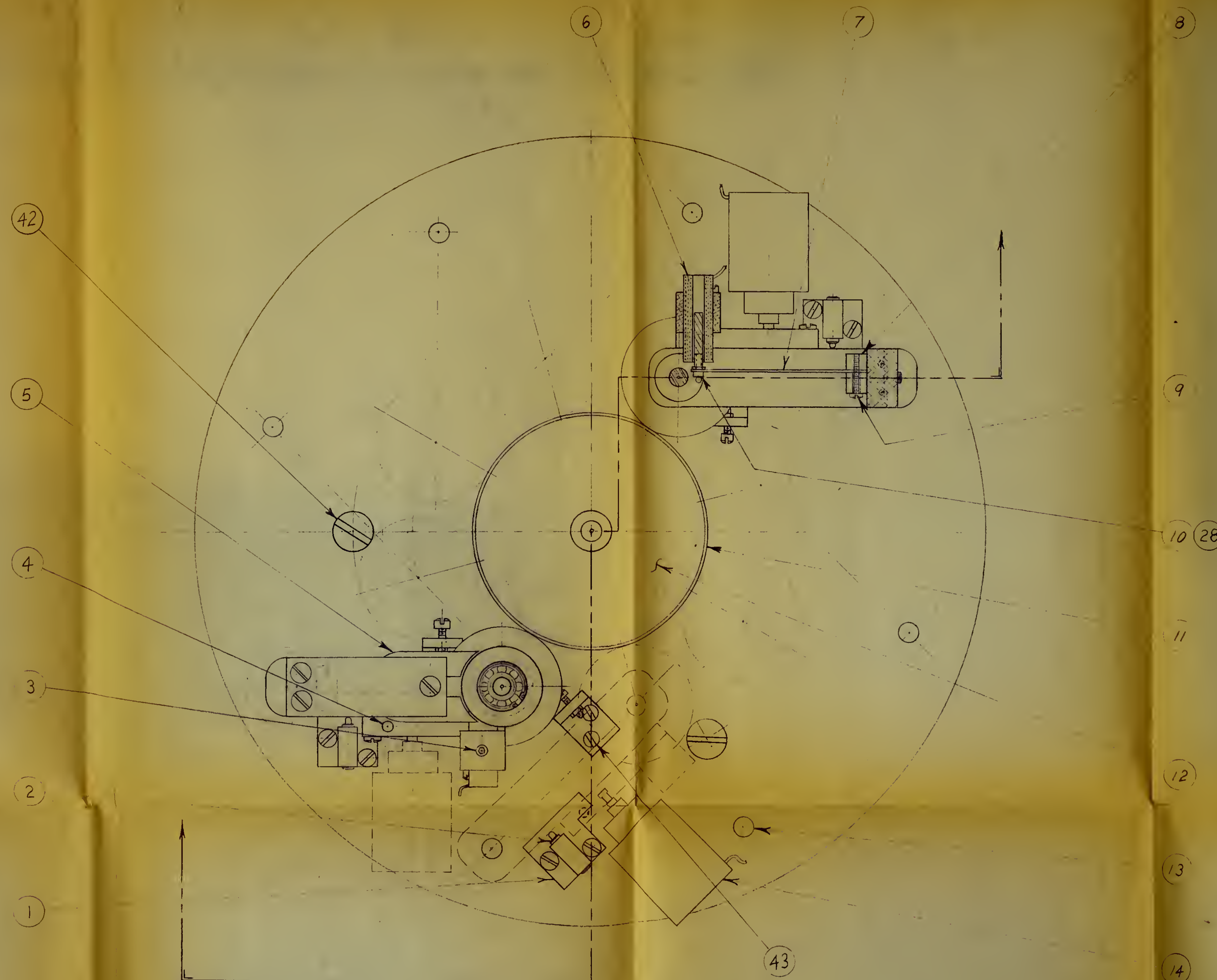
	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	McWalker	3-9-62

HARVARD COLLEGE OBSERVATORY

CAMBRIDGE 38 MASSACHUSETTS

TITLE JIG, TEST STATION CALIBRATION

SCALE 1/1 NUMBER B-5105 REV LTR


6
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REVISIONS			
REV	DESCRIPTION	DATE	APPROVED

43	16		SCREW, 2-56NC-2 x 3/8 LG, FLAT HD., SS.
42	3		SCREW, 1/4-20NC-2 x 3/4 LG., BIND.HD., S.S.
41	8		NUT, HEX, 6-40NF-2, S.S.
40	8		SCREW, 6-40NF-2 x 3/8 LG, FIL.HD., S.S.
39	8	A-5223	STOP, TEST STATION.
38	3	A-5212	BLOCK, BASE PLATE SUPPORT.
37	32		SCREW, #4-40NC-2 x 1/4 LG., BIND.HD., SS.
36	16		SCREW, #4-40NC-2 x 1/2 LG, BIND.HD., S.S.
35	8	B-5216	BRACKET, TRANSDUCER.
34	1	B-5215	PLATE, BASE.
33	1	B-5214	WHEEL, MAGNET, DRIVEN.
32	130		MAGNET, ARNOLD ENG. # 3241.
31	1		SHAFT, DRIVE, PIC # A6-20.
30	10	A-5213	BEARING, TEFLON, FLANGED.
29	16		WASHER, THRUST.
28	8		NUT, HEX, # 1-72NF-2, SS.
27	8	A-5211	SHAFT, TEST BEARING.
26	8	A-5210	BEARING, TEFLON, PLAIN.
25	10		SET SCREW, #2-56 x 1/8 LG, SK.HD., NO-MAR
24	8		SPACER, PIC # B8-12
13	8	B-5209	BLOCK, BEARING TEST STATION.
12	8	B-5208	BRACKET, MAGNET.

NO	QUAN	NUMBER	DESCRIPTION
43	16		SCREW, 2-56NC-2 x 3/8 LG, FLAT HD., S.S.
42	3		SCREW, 1/4-20NC-2 x 3/4 LG., BIND. HD., S.S.
41	8		NUT, HEX, 6-40NF-2, S.S.
40	8		SCREW, 6-40NF-2 x 3/8 LG, FIL. HD., S.S.
39	8	A-5223	STOP, TEST STATION.
38	3	A-5212	BLOCK, BASE PLATE SUPPORT.
37	32		SCREW, #4-40NC-2 x 1/4 LG., BIND. HD., S.S.
36	16		SCREW, #4-40NC-2 x 1/2 LG, BIND. HD., S.S.
35	8	B-5216	BRACKET, TRANSDUCER.
34	1	B-5215	PLATE, BASE.
33	1	B-5214	WHEEL, MAGNET, DRIVEN.
32	130		MAGNET, ARNOLD ENG. # 3241.
31	1		SHAFT, DRIVE, PIC # A6-20.
30	10	A-5213	BEARING, TEFLON, FLANGED.
29	16		WASHER, THRUST.
28	8		NUT, HEX, # 1-72NF-2, S.S.
27	8	A-5211	SHAFT, TEST BEARING.
26	8	A-5210	BEARING, TEFLON, PLAIN.
25	10		SET SCREW, #2-56 x 1/8 LG, SK. HD., NO-MAR
24	8		SPACER, PIC # B8-12
23	8	B-5209	BLOCK, BEARING TEST STATION.
22	8	B-5208	BRACKET, MAGNET.

NUMBER D-5101 REV

NO	QUAN	NUMBER	DESCRIPTION
21	24		SCREW, #4-40NC-2 x 7/8 LG., FIL. HD., S.S.
20	8		SCREW, #4-48NF-2 x 3/4 LG., FIL. HD., S.S.
19	24		SNAP RING, TRUARC # 5103-25.
18	8		SNAP RING, TRUARC # N5001-62.
17	8		TEST BEARING.
16	8	B-5207	HOUSING, TEST BEARING.
15	8	A-5206	WHEEL, DRIVEN.
14	8		SOLENOID, GUARDIAN 22 INT. 24DC.
13	8		PIN, DOWEL, PIC # A6-13.
12	1	B-5205	WHEEL, DRIVING.
11	1		O-RING, PARKER # 2-334, BUNA-N.
10	8	A-5204	KNIFE EDGE.
9	16		SCREW, #1-72NF-2 x 1/2 LG., BIND. HD., S.S.
8	8	A-5203	BLOCK, SPRING.
7	8	A-5202	SPRING.
6	8		TRANDUCER, LINEARSYN # 595DT-050.
5	8		MAGNET, LOAD.
4	8		PIN, STOP, PIC # A1-13.
3	8		SET SCREW, NO-MAR #2-56 x 5/32 LG.
2	8		PLUNGER, VLIER # S51.
1	8	B-5201	BRACKET, PLUNGER.

UNLESS OTHERWISE SPECIFIED DIMENSIONS IN INCHES - TOLERANCES ON

FRACTIONS ± #   DECIMALS ± #   ANGLES ± #

MATERIAL & SIZE #

FINISH #

APPLICATION: NEXT ASSEMBLY | USED ON

	SIGNATURE	DATE
APPR	NLH	5/17/62
CHECK		
DRAWN	McWalker	1/21/61

HARVARD COLLEGE OBSERVATORY

CAMBRIDGE 38 MASSACHUSETTS

TITLE TEST APPARATUS, BEARING, HIGH VACUUM.

SCALE 1/1   NUMBER D-5101   REV LTR